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FIRST EDITION

Practical Astronomy

PART 1

790 A

SCRANTON, PA.
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PRACTICAL ASTRONOMY

(PART 1)

INTRODUCTION

THE GREEK ALPHABET

1. In works on astronomy, several letters of the Greek alphabet are used very commonly, both to represent the different stars of a constellation and to represent certain quantities. The letters of this alphabet and their names are as follows:

α alpha	ι iota	ρ rho
β beta	κ kappa	σ sigma
γ gamma	λ lambda	τ tau
δ delta	μ mu	υ upsilon
ϵ epsilon	ν nu	ϕ phi
ζ zeta	ξ xi	χ chi
η eta	o omicron	ψ psi
θ theta	π pi	ω omega

The brightest star in a constellation is generally denoted by α, the next brightest by β, and so on.

DEFINITIONS

NOTE.—A few of the subjects contained in this Section were treated in *Geometry* and in *Transit Surveying*. Their treatment is repeated here both for convenience of reference and for completeness.

2. Astronomy is the science that treats of the heavenly bodies.

This science is divided into five branches, namely:

(*a*) **Descriptive astronomy,** which is an orderly statement of astronomical facts ascertained by systematic observation, and of the laws derived from those facts.

(*b*) **Spherical astronomy,** which is an application of geometry and trigonometry to the determination of the relative positions of the heavenly bodies (the earth included).

(*c*) **Practical astronomy,** which treats of the methods of making astronomical observations, and of deducing from them the values of certain important quantities used in navigation and surveying.

(*d*) **Celestial mechanics,** which treats of the motions of the heavenly bodies as depending on the laws of dynamics.

(*e*) **Astrophysics,** called also **physical astronomy** which treats of the physical condition and chemical constitution of the heavenly bodies.

3. The accurate determination of the bearing of lines on the earth's surface and of the latitude and longitude of points depends on the principles of practical astronomy. These principles will therefore be developed quite fully in the present text. But before proceeding to do so, it will be necessary to state some elementary geometrical rules and principles of which astronomy makes frequent use.

MEASURES OF AN ANGLE

4. An angle is measured by the arc of a circle whose center is at the vertex and whose ends are on the sides of the angle. This arc is usually graduated, or measured, in one of the three ways explained below.

5. Arc, or Degree, Measure.—In this method of measuring an angle, the whole circumference of which the measuring arc is a part is divided into 360 equal parts, called **degrees**; each degree is subdivided into 60 equal parts, called **minutes**; and each minute into 60 equal parts, called **seconds**. The magnitude of an angle is then expressed by the number of degrees, minutes, and seconds that its measuring arc contains. This is the familiar method explained in

geometry. An angle so expressed is frequently said to be expressed **in arc**, or **in degrees** (minutes and seconds being included).

6. **Time Measure.**—In this method, which is much employed in astronomy, the circumference is divided into 24 equal parts, called **hours**; each hour into 60 equal parts, called **minutes**; and each minute into 60 equal parts, called **seconds**. An angle expressed in hours, minutes, and seconds is frequently said to be expressed **in time**. Hours, minutes, and seconds of time are denoted, respectively, by the abbreviations, hr., min., sec., or, more simply, h., m., s.

7. **Circular Measure.**—In the third method of measuring an angle, the magnitude of the angle is expressed by stating how many times the measuring arc contains the radius; that is, the angle is measured by the ratio of the length of the arc that subtends it to the length of the radius of the arc. An angle so expressed is said to be expressed **in circular measure**, or **in radians**. The name **radian** is given to an angle the length of whose subtending arc is equal to that of the radius. The circular measure of such an angle is equal to unity, and for this reason the radian is said to be the unit of circular angle measure.

CONVERSION OF ARC MEASURE INTO TIME MEASURE, AND VICE VERSA

8. **By Direct Multiplication and Division.**—Since the circumference of a circle contains 360° when expressed in arc, and 24 hours when expressed in time, it follows that an arc of 1 hour contains $\frac{1}{24}$ of 360°, or 15°. Also, 1 minute of time contains $\frac{1}{60}$ of 15°, or 15′; and 1 second of time contains $\frac{1}{60}$ of 15′, or 15″. From these relations, time can be converted into arc, and arc into time, by a simple process of multiplication and division. This process was fully explained and illustrated in *Transit Surveying*, Part 2, and need not be repeated here.

9. **By Means of Tables.**—Instead of performing the arithmetical operations just referred to, which are somewhat

laborious, Table I at the end of this Section may be used. This table contains the value, in hours and minutes, of any number of degrees, from 1 to 360, and also the value, in time measure, of any number of minutes of arc. The seconds of arc must be reduced to seconds of time by dividing by 15. The use of this table is illustrated by the following examples:

EXAMPLE 1.—To change 278° 18′ 42″ to time measure.

SOLUTION.—Using Table I, we find

Opposite 278° in column 5	$18^h\ 32^m\ 0.0^s$
Opposite 18′ in column 1	1 12.0
Dividing 42″ by 15	2.8
Hence, adding the three numbers	$18^h\ 33^m\ 14.8^s$ Ans.

EXAMPLE 2.—To change $7^h\ 40^m\ 55^s$ to arc measure.

SOLUTION.—Using Table I, we find

Opposite $7^h\ 40^m$ in column 2	115° 0′ 0″
Opposite 52^s in column 1	13 0
Multiplying the remaining 3^s by 15	45
Hence, adding the three numbers	115° 13′ 45″ Ans.

EXAMPLES FOR PRACTICE

1. Change 18° 10′ 45″ to time measure. Ans. $1^h\ 12^m\ 43^s$
2. Change 351° 0′ 30″ to time measure. Ans. $23^h\ 24^m\ 2^s$
3. Change $3^h\ 20^m\ 40^s$ to arc measure. Ans. 50° 10′ 0″
4. Change $23^h\ 52^m\ 10^s$ to arc measure. Ans. 358° 2′ 30″

CONVERSION OF ARC MEASURE INTO CIRCULAR MEASURE, AND VICE VERSA

10. Since the whole circumference of a circle is approximately 6.28318 times the radius, it follows that the 360° of the measuring circumference are equivalent to 6.28318 radians. Hence, 1 radian contains 360 ÷ 6.28318 = 57.29578°, or, near enough for most practical purposes, 57.3°. Hence, if

A_d = angle expressed in degrees, and

A_r = same angle expressed in radians,

then

$$A_d = 57.3\,A_r \qquad (1)$$

$$A_r = \frac{A_d}{57.3} = .0175\,A_d \qquad (2)$$

In applying formula **2**, minutes and seconds must be reduced to decimals of a degree.

As radians are frequently used in connection with the very small angles that enter into astronomy, it is useful to remember that the value of 1 radian, expressed in seconds of arc, is $3,600 \times 57.29578 = 206,264.8''$.

EXAMPLE 1.—To change the angle .0234 radian to arc measure.

SOLUTION.—Here $A_r = .0234$. By formula **1**,

$$A_d = .0234 \times 57.3° = 1.3408° = 1° \; 20' \; 26.9''. \text{ Ans.}$$

EXAMPLE 2.—To change 59° 52′ 30″ to circular measure.

SOLUTION.—Here $A_d = 59° \; 52' \; 30'' = 59.875°$. By formula **2**,

$$A_r = 59.875 \div 57.3 = 1.045 \text{ radians. Ans.}$$

EXAMPLES FOR PRACTICE

1. Change 1.25 radians to arc measure. Ans. 71° 37′ 30″
2. Change $\frac{1}{12}$ radian to arc measure. Ans. 4° 46′ 30″
3. Change 3° 10′ 30″ to circular measure. Ans. 0.0554 radian, nearly
4. Change 15° 24′ to circular measure. Ans. 0.2688 radian, nearly

THE SPHERE

DEFINITIONS

11. In geometry, a **sphere** is defined as a solid bounded by a surface every point of which is equidistant from a point within, called the **center**. The surface of such a solid is properly called a **spherical surface**, but for the sake of brevity a spherical surface is often called a sphere, just as the word circle is used instead of the longer word circumference.

12. A **radius** of a sphere is a straight line drawn from the center to the surface. A straight line passing through the center and terminated at both ends by the surface is called a **diameter** of the sphere.

13. A sphere may be generated by the revolution of a semicircle about its diameter. For, if the semicircle ACB,

Fig. 1, is turned about its diameter AB, any point P on the semicircle is at a constant distance oP from the center o. Consequently, during the revolution, every point on the semicircle lies on a sphere whose center is o and whose radius is oP.

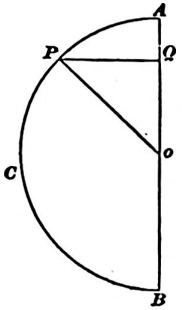

FIG. 1

14. Let Q, Fig. 1, be a fixed point in the diameter AB, and let QP be drawn perpendicular to AB. Then, during the revolution of the semicircle, QP lies always in the same plane, and the point P describes a circle whose center is Q. Hence, every plane section of a sphere is a circle.

15. A section of a sphere made by a plane passing through the center is called a **great circle.** A section made by a plane not passing through the center is called a **small circle.** Thus, $ABA'B'$ and $BPB'P'$, Fig. 2, are great circles, because their planes pass through the center C of the sphere; while $aba'b'$ and cc' are small circles, because their planes do not pass through C. A great circle divides the sphere into two equal parts, called **hemispheres.**

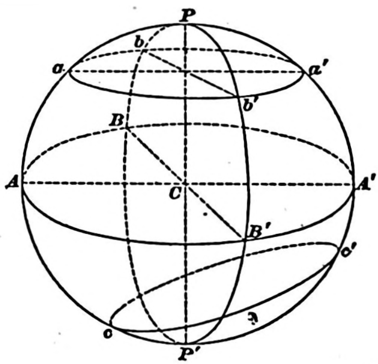

FIG. 2

16. A straight line through the center of either a great or a small circle, and perpendicular to the plane of the circle, is called the **axis** of the circle. The points where the axis of a circle meets the sphere are called the **poles** of the circle. Thus, PP', Fig. 2, is the axis of the great circle $ABA'B'$ and of the small circle $aba'b'$; the points P and P' are the poles of these circles. The axis of any circle of a sphere passes through the center of the sphere.

17. If any great circle of a sphere is taken as a **primary, or fundamental,** circle, great circles passing through its poles are called its **secondaries.** Thus, if $A\,B\,A'\,B'$, Fig. 2, is taken as a primary circle, $P\,B\,P'\,B'$, a great circle passing through the poles P and P', is one of its secondaries.

It is evident that the plane of a great circle is perpendicular to the plane of each of its secondaries; it follows that, if one circle is a secondary to another, the latter is also a secondary to the former. Thus, the circle $A\,B\,A'\,B'$, Fig. 2, is a common secondary to the two circles $A\,P\,A'\,P'$ and $B\,P\,B'\,P'$.

18. The angle between two great circles, called a **spherical angle,** is the angle between their planes, and is measured by the angle between two lines drawn, one in each plane, perpendicular to the line in which the planes intersect. Each of these lines must meet the line in which the planes intersect at the same point. Thus, the angle $A'\,P\,B$ between the great circles $A\,P\,A'\,P'$ and $B\,P\,B'\,P'$, Fig. 2, is measured by the angle $A'\,C\,B$, in which $C\,A'$ lies in the plane of $A\,P\,A'\,P'$ and is perpendicular to the intersection $C\,P$ of the two planes at C; while $C\,B$ lies in the plane of $B\,P\,B'\,P'$, and is also perpendicular to that intersection at the same point C. Now, the angle $A'\,C\,B$ is measured by its intercepted arc $A'\,B$. Hence, the angle between the circles $A\,P\,A'\,P'$ and $B\,P\,B'\,P'$ is measured by the arc $A'\,B$ that they intercept on their common secondary $A\,B\,A'\,B'$. This may be stated as a general principle as follows:

The angle between two great circles is measured by the arc that they intercept on their common secondary.

19. The **angular distance** between two points on a sphere is the angle that they subtend at the center of the sphere.

20. A **spherical triangle** is a portion of a sphere bounded by three arcs of great circles.

21. **Parallel circles** of a sphere are those whose planes are parallel.

PROPERTIES OF SPHERICAL CIRCLES

22. Every point on a circle of a sphere is at a constant angular distance from either pole of the circle. For, during the revolution of the generating semicircle, Fig. 1, the arc AP remains constant, and A is the pole of the circle described by the point P.

23. The shortest distance, measured on the surface, between two points on a sphere, is the arc of the great circle joining the two points.

24. Through two points on a sphere that are not the extremities of a diameter of the sphere, one and only one great circle can be described.

25. Through two points on a sphere that are not the extremities of a diameter of the sphere, an infinite number of small circles can be described.

POSITION OF A POINT ON A SPHERE

26. Let $A O A'$, Fig. 3, be a fixed great circle whose axis is PP', and let O be a fixed point on this circle. If we conceive the sphere to be generated by the revolution of a semicircle about its diameter PP', it is evident that, during a complete revolution, the generating semicircle passes once and only once through every point on the sphere. Let $PXBP'$ be the position of the generating semicircle in which it passes through the point X. This position of the generating semicircle may be fixed, with respect to O, by measuring the arc OB. Let QXQ' be a plane parallel to the plane $A O A'$; then the plane QXQ' and the semicircle PXP' can intersect only in the

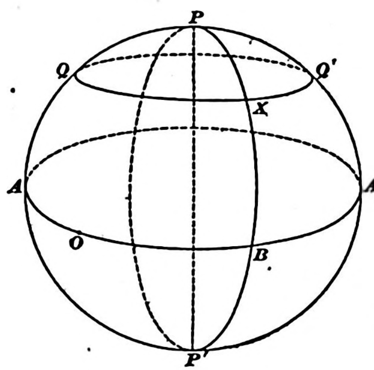

FIG. 3

one point X. Hence, the position of the point X can be determined by fixing the position of the plane QXQ' and the position of the semicircle PXP'. The position of the semicircle PXP' is fixed by measuring the arc OB; the position of the plane QXQ' can be fixed by measuring how far it is above or below the plane AOA'. Manifestly, if the arc BX is measured, it will fix the height of the plane QXQ' above the plane AOA'. Thus, the position of the point X with respect to O may be fixed by measuring the arcs OB and BX.

Suppose that X and X' are two points on a sphere, the position of X being fixed by the arcs OB and BX, while the position of X' is fixed by the arcs OB' and $B'X'$. Then, if OB is equal to OB', the points X and X' lie on the same circle passing through P and P'; that is, on the same secondary to AOA'. If BX is equal to $B'X'$, the points X and X' are on the same small circle parallel to AOA'.

The position of a point, then, is fixed by specifying: (1) on which of the secondaries to a fixed circle AOA' it lies, and on which of the halves of that secondary it lies; and (2) on which of the parallels to AOA' it lies.

27. The method here described is employed for fixing the position of a place on the earth's surface, the points P and P' being the poles of the earth. The great circle $AOBA'$, perpendicular to PP', is called the **equator**, and the arc POP' (not shown) is called the **principal meridian**, or **reference meridian**. The arcs OB and BX are called the **longitude** and **latitude**, respectively, of the point X. The meridian that passes through the Royal Observatory at Greenwich, near London, England, is adopted as a principal meridian for some purposes; that passing through the dome of the new observatory at Washington is the principal meridian for the United States.

THE CELESTIAL SPHERE

28. Apparent Conditions.—To one who observes the heavens at night, the celestial bodies appear to be bright points attached to the inner surface of a vast hollow spherical dome, whose center is at the observer's eye.

A little reflection, however, is sufficient to establish the fact that the heavenly bodies are not all equidistant from the observer's eye, and are not attached to any surface. Indeed, we have no direct means of estimating the distances of all these bodies; all that we can directly observe is their relative directions. Most astronomical instruments determine merely the relative directions of the heavenly bodies. It is very important, therefore, to have a convenient mode of representing these relative directions.

29. Assumed Conditions.—Imagine a vast spherical surface to be described enclosing all the heavenly bodies, and having its center at the observer's eye; this imaginary surface is called the **celestial sphere.** The heavenly bodies are so enormously remote that in comparison with this sphere the whole earth is a mere dot or point. Any point on the earth may therefore be regarded as the center of the celestial sphere, since from all such points the apparent directions of the heavenly bodies are practically the same.

30. The Stars.—To any observer at the center, this sphere appears to be covered with numerous **stars,** some of which rise and set regularly, while others are nearly stationary. The stars are aggregated into more or less definite groups called **constellations.** A very little watching will convince the observer of the important fact that the forms of the constellations, or the relative positions of the stars on the celestial sphere, do not change. Maps of the constellations made centuries ago do not materially differ from those made at present.

The stars are fixed in their positions on the celestial sphere, and it is the apparent rotation of this sphere as a whole that causes them to appear to rise and set.

31. There is but one-half of the celestial sphere that is visible to the observer at one time, since the earth under foot intercepts the other half from view; but if we imagine the earth to become transparent and the light of the sun to be extinguished, the observer would behold the heavens entirely surrounding him, below as well as above, and covering the entire surface, all the constellations of the sky would shine out, each immovably fixed in its proper position on the sphere.

32. If the observer could cause the earth's axis to become a real visible line produced in both directions until it met the celestial sphere, he would perceive that the entire spherical surface bearing the constellations was apparently turning slowly about this axis from east to west, completing one revolution in about 24 hours. Further knowledge would teach him that it is not the enormous sphere that is turning about the earth's axis, but that the earth itself, by a uniform rotation from west to east, brings different points of the celestial sphere successively overhead.

33. Unfortunately, the observer cannot see the whole surrounding sphere at one time. In the night-time, the earth cuts off one-half of it; and in the day-time, the overpowering brilliancy of the sun renders the stars invisible to the unaided eye. It should be remembered, however, that the sphere is about us no less during the day than during the night, and that at any hour of the day, could the light of the sun be blotted out, the constellations would appear to us each in its proper place.

POSITION OF A BODY ON THE CELESTIAL SPHERE

34. The exact position of any point on the earth's surface is known when the latitude and longitude of the point are known (Art. 27). For the purpose of defining latitude

and longitude, certain imaginary circles on the earth's surface, of which the most important are the equator and the principal meridian, are used as reference circles. In exactly the same way, certain reference circles are conceived to be drawn on the celestial sphere, and the positions of heavenly bodies are referred to them.

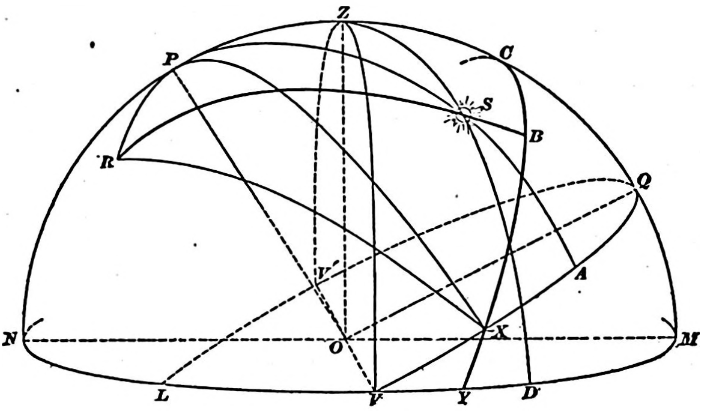

FIG. 4

Fig. 4 represents the celestial hemisphere, all the reference circles that are used in astronomy being drawn on it. The definitions of these circles should be learned and thoroughly understood, as they are indispensable in the study of practical astronomy.

THE EQUINOCTIAL SYSTEM OF CIRCLES

35. The earth's axis, when produced indefinitely in both directions, is called the **axis** of the celestial sphere, or of the heavens. The point in which the axis of the earth produced toward the north pierces the celestial sphere is called the **north pole** of the sphere, or of the heavens. The point in which the earth's axis produced toward the south pierces the celestial sphere is called the **south pole** of the sphere, or of the heavens. In Fig. 4, OP is one-half of the earth's axis, and P is the north pole of the sphere. The south pole is not shown in the figure.

36. The **celestial equator** is the great circle in which the plane of the earth's equator intersects the celestial sphere. In Fig. 4, $VQV'L$ is part of the celestial equator.

37. All great circles passing through the north and the south pole of the celestial sphere are called **hour circles.** It follows that hour circles are secondaries to the celestial equator; also, that the poles of the celestial equator coincide with the poles of the celestial sphere. Thus, in Fig. 4, PX, PA, and PQ are hour circles.

38. The celestial equator divides the celestial sphere into two hemispheres: that containing the north pole is called the **northern hemisphere**; the other, the **southern hemisphere.**

39. The sun in its apparent motion over the celestial sphere crosses the equator, passing from the southern to the northern hemisphere, on the 21st of March. The point at which the sun appears to cross the equator as it passes from the southern to the northern hemisphere is called the **vernal equinox.** In Fig. 4, $YXBC$ is a part of the apparent path of the sun over the celestial sphere; the point X is the vernal equinox. The position of the vernal equinox will be clearly understood from the following explanation.

The sun appears to move slowly over the celestial sphere among the stars from west to east, and takes just 1 year to move entirely around the sphere. The celestial equator is a circle drawn on the celestial sphere 90° from the poles, just as the earth's equator is a circle on the earth 90° distant from the north and south poles. Now, in passing around the sphere, the sun crosses this equator twice each year; on the 21st of March it crosses it in passing from the southern to the northern hemisphere; and on the 22d of September, in passing from the northern to the southern hemisphere. In Fig. 5, AB represents a part of the celestial equator; the whole figure shows a little band of the celestial sphere lying along the equator. The line CDE shows the path of the sun among the stars between March 21 and September 22. On March 21, the sun crosses the celestial equator

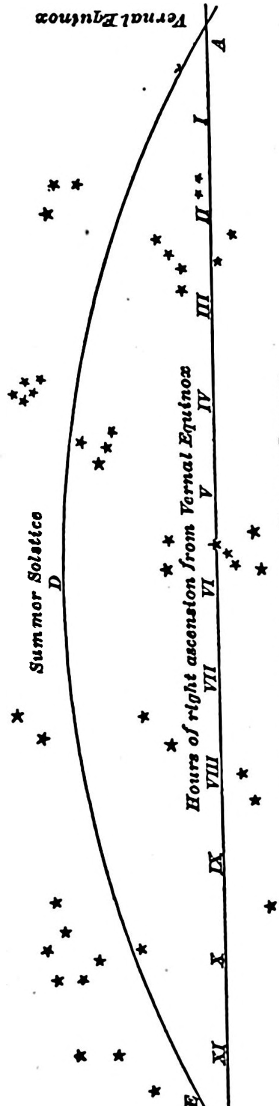

FIG. 5. THE SUN'S APPARENT PATH IN SUMMER

at A, and this point, which is the intersection of the path of the sun with the equator, is the vernal equinox.

40. The hour circle passing through the vernal equinox is called the **equinoctial colure.** In Fig. 4, PX is the equinoctial colure.

41. The **right ascension** of a celestial body is the arc of the celestial equator measured eastward from the vernal equinox to the hour circle passing through the body. Thus, in Fig. 4, XA is the right ascension of the body S.

42. The **declination** of a heavenly body is its angular distance north or south of the celestial equator, and is measured by the arc of the hour circle passing through the body and intercepted between it and the equator. Thus, in Fig. 4, AS is the declination of the body S. The declination of a heavenly body is considered positive or negative (+ or −) according as the body is north or south of the celestial equator.

43. Right ascension and declination are exactly similar to terrestrial longitude and latitude, respectively; the celestial equator corresponds to the earth's equator, and the equinoctial colure to

the principal meridian. When the right ascension and declination of a heavenly body are known, its position on the celestial sphere is definitely fixed.

44. Except for very minute motions, the stars do not change their positions on the celestial sphere; it therefore follows that the right ascension and declination of every star remains sensibly constant during long periods of time. The sun, moon, and planets, however, are continually in motion on the sphere; hence, their right ascension and declination are constantly changing.

45. The **polar distance** of a heavenly body is its angular distance from the nearer pole, and is measured by the arc of the hour circle intercepted between the pole and the body. The polar distance is, therefore, the complement of the declination. In Fig. 4, SP is the polar distance of S.

THE DIURNAL MOTION

46. An observer standing at night in the middle of a great prairie or on a ship on the ocean sees about him an apparently level surface surmounted by the visible hemisphere of the sky. The great circle in which this surface and the sky appear to meet is the **apparent horizon**, which for brevity is usually called *the horizon*. We know, however, that the surfaces of the prairie and ocean are not really plane surfaces, but a portion of the curved spherical surface of the earth. For astronomical purposes, the **plane of the horizon** is a plane tangent to the earth's surface at the point occupied by the observer.

47. The **celestial horizon** is the great circle in which the plane of the horizon intersects the celestial sphere. In astronomy, the term *horizon* is generally understood to mean the celestial horizon. In Fig. 4, the circle NVM is the celestial horizon.

48. The **zenith** of a point on the earth's surface is a point in which a line passing through the center of the earth and the given point pierces the celestial sphere; in Fig. 4,

Z is the zenith. The point in which the same line pierces the celestial sphere below the given point is called the **nadir** of that point. The zenith and nadir of a point occupied by an observer are referred to, respectively, as the zenith and nadir of the observer. The zenith and nadir are the poles of the horizon. The prolongation of the plumb-line is the axis of the horizon, and meets the celestial sphere in the zenith directly overhead, and in the nadir underfoot.

The position of the zenith and that of the horizon on the celestial sphere depend on the position of the observer on the earth's surface, and are, therefore, different for observers differently located.

49. If the axis about which the celestial sphere revolves were a luminous straight line, the observer, standing on the horizon plane and facing north, would see this line piercing the plane of the horizon and extending to the north pole of the heavens. On account of the apparent rotation of the whole sphere about this axis, the various constellations would appear above the horizon plane in the east, pass across the sky in small circles parallel to the equator, and finally disappear below the horizon plane in the west.

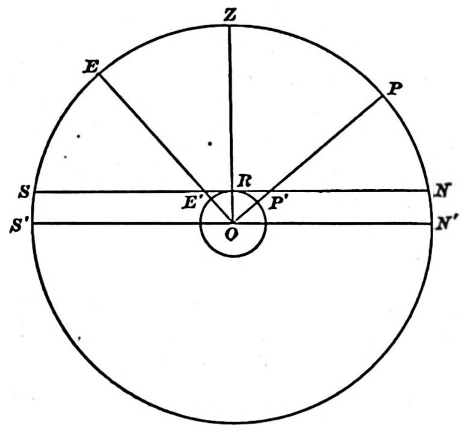

FIG. 6

50. Fig. 6 represents a section of the earth and the celestial sphere made by a plane passing through the north and south poles of the earth and the observer's station R; it is therefore a meridian plane. SZN is an arc of the celestial sphere; Z is the zenith; and SN, the horizon. Since the distance between

O and R is inappreciable compared with the distances of these two points from the surface of the celestial sphere, the observer's position R may be taken as coinciding with the center O of the earth; and the plane $S' O N'$, passed through O parallel to the plane $S R N$, as coinciding with the horizon plane (Art. 29). It is assumed that $O E' E$ is the equator and $O P' P$ the axis both of the earth and of the celestial sphere. The angle $E' O R$ is the latitude of the observer, or his angular distance from the equator, and since it equals $Z O E$, which is measured by the arc $E Z$, it follows that the arc of the meridian intercepted between the zenith and the celestial equator measures the observer's latitude. The angle $P O N'$, measured by the arc $N' P$, or, practically, by $N P$, equals the angle $Z O E$, for each of these angles is the complement of $P O Z$; hence, the angular elevation of the north pole of the heavens above the horizon plane is equal to the latitude of the observer. This angular elevation is called the **altitude** of the pole. We have, then, the following important principle:

The latitude of an observer is equal to the altitude of the pole above the observer's horizon. (See *Transit Surveying*, Part 2.)

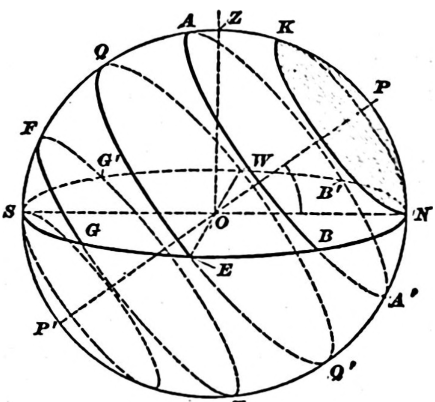

FIG. 7

51. The apparent motion of the stars will be understood by referring to Fig. 7, which represents the celestial sphere. The earth is represented by the point O at the center of the sphere; $S E N$ is the horizon plane; $P P'$, the polar axis; $E Q W Q'$, the celestial equator; and $N K$, $B A$, $E Q$, and $G F$, the apparent paths pursued by the stars as the apparent rotation of the celestial sphere about $P P'$ carries them around the sky. A star between the pole and the equator will be

brought above the horizon at some point B, and after being carried across the sky along the path BAB', will finally set at B'. A star whose polar distance is PN will, by the rotation of the celestial sphere, be carried about the axis on a small circle NK that just touches the horizon plane at N, and hence it will never rise nor set. Similarly, all stars whose polar distance is less than PN will remain always above the horizon. A star exactly at P would have no motion at all. There is no star exactly at either pole. The closest star to the north pole is **Polaris**, often called the **pole star** and the **north star**, whose polar distance is about 1° 13′.

Any star south of the equator will rise above the horizon at some point, as G, and remaining visible but a short time, will be carried across the sky on the small circle GFG'. A star whose south polar distance is less than $P'S$ will never appear above the horizon.

52. The small circle KN is called the **circle of perpetual apparition**, while the small circle $P'S$ is called the **circle of perpetual occultation.** Since the angle PON, measured by the arc NP, is equal to the elevation of the pole above the horizon, which is equal to the latitude of the observer, it follows that the polar distance of any point in the circle of perpetual apparition, or in the circle of perpetual occultation, is equal to the latitude of the observer.

53. It is very important that this apparent motion of the stars should be clearly understood. It should be borne in mind that the stars are immovably fixed on the celestial sphere, and that this sphere appears to turn as a whole from east to west. If possible, a few evenings should be spent in studying the motion from the sky itself, for when it has been observed actually taking place in the heavens, it is not easily forgotten. For this purpose, go out on some clear evening and, facing toward the north, trace out the constellation of the Great Dipper, called by astronomers Ursa Major, Fig. 8. If a line is drawn through the first two stars in the bowl of the dipper and produced as shown in the figure, it will pass nearly through the north star. or Polaris. Next

make a diagram of several of the brighter stars about the pole, and then, after an interval of 3 or 4 hours, compare this diagram with the stars in the sky. It will at once be per-

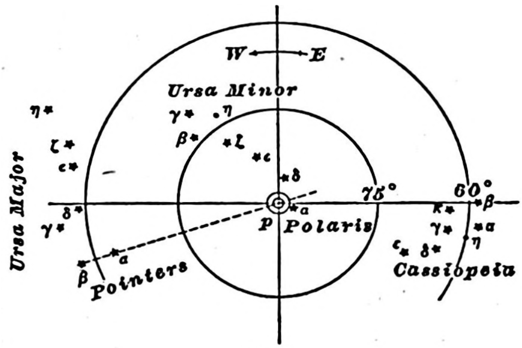

FIG. 8

ceived that the stars have moved about the pole in the manner described above. A few evenings spent in observation will suffice to fix the nature of this motion clearly in the mind.

THE HORIZON SYSTEM OF CIRCLES

54. It has been explained (Art. 43) that the position of a body on the celestial sphere may be exactly indicated by referring it to the celestial equator and the vernal equinox. For many purposes, however, it is more convenient to refer the body to the horizon as a primary circle.

55. The **celestial meridian** of an observer is the great circle of the celestial sphere that passes through the poles and the zenith of the observer. This circle passes also through the nadir, and is secondary to the horizon. In Fig. 4, *NPZCQM* is one-half of the celestial meridian.

56. The celestial meridian cuts the horizon in two points called, respectively, the **north point** and the **south point** of the horizon. The points on the horizon midway between the north and the south point are called the **east point** and the **west point**, respectively. In Fig. 4, *N* is the north

point; M, the south point; V', the east point; and V, the west point of the horizon.

57. A **vertical circle** is any circle passing through both the zenith and the nadir. It follows that all vertical circles are secondaries to the horizon. In Fig. 4, ZN, ZV', ZQM, ZD, and ZV are portions of vertical circles.

58. The vertical circle that passes through the east and the west point is called the **prime vertical.** The prime vertical is at right angles to the meridian. In Fig. 4, $V'VZ$ is the prime vertical.

59. The **altitude** of a heavenly body is its angular distance from the horizon, and is measured along the vertical circle passing through the body. In Fig. 9, in which SEN is the horizon and SZN the meridian, HM is the altitude of the star M. In Fig. 4, DS is the altitude of S.

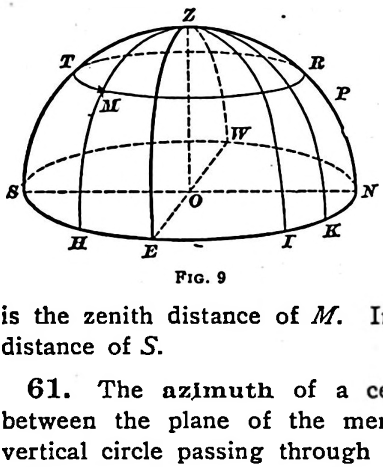

FIG. 9

60. The **zenith distance** of a celestial body is the angular distance from the body to the zenith, and is measured on the vertical circle passing through the body. The zenith distance is the complement of the altitude. In Fig. 9, in which Z is the zenith, MZ is the zenith distance of M. In Fig. 4, SZ is the zenith distance of S.

61. The **azimuth** of a celestial body is the angle between the plane of the meridian and the plane of a vertical circle passing through the body. It is measured either from the south point toward the west, or from the north point toward the east, along the horizon. In Fig. 9, in which N and S are, respectively, the north and south points, NH is the azimuth of M, reckoned from the north toward the east, and $SWNEH$ is the azimuth of M, reckoned from the south toward the west. Similarly, in

Fig. 4, *MD* is the azimuth of *S* measured from the south toward the west.

62. It is evident that the zenith, meridian, and horizon are fixed with reference to the observer, but are not fixed with reference to the celestial sphere. The zenith traces out a small circle on the celestial sphere as the sphere turns on its axis, and hence the altitudes and azimuths of all heavenly bodies are constantly changing. The altitude and azimuth serve to indicate the apparent direction of a body with reference to the observer at any given instant.

ANOTHER METHOD OF FIXING THE POSITION OF A HEAVENLY BODY

63. In this method, one circle from each of the preceding systems is employed as a circle of reference.

64. The **hour angle** of a star is the arc intercepted on the equator between the meridian and the foot of the hour circle passing through the star. It is measured from the meridian toward the west. Hour angles are usually expressed in time measure. In Fig. 4, *QA* is the hour angle of the body *S*.

The position of a star is indicated in this method by stating the values of the hour angle and declination.

65. On account of the uniform rotation of the celestial sphere, the hour angle increases uniformly while the declination remains constant. The hour circle passing through the star makes a complete revolution around the sky once in every 24 hours, sidereal time (Art. **67**). It follows that the hour angle of the star is simply the time that has elapsed since the star was on the meridian. This affords an easy way of determining the hour angle by observation, as will be explained elsewhere.

COMPARISON OF THE THREE SYSTEMS

66. Fig. 4 represents the celestial hemisphere visible to an observer whose horizon is *NDM*: *Z* is the zenith,

	Equinoctial System	Horizon System	Hour-Angle System
Primary circle of reference	Equator VXQ.	Horizon $NVDM$.	Equator VXQ.
Secondary circle of reference	Equinoctial colure PX.	Meridian $PZQM$.	Meridian $PZQM$.
Poles of the primary circle	North pole P and south pole.	Zenith Z and nadir.	North pole P and south pole.
The position is fixed by	Right ascension XA, + toward the east. Declination AS, + above the equator; or polar distance PS.	Azimuth MD, + toward the west. Altitude SD; or zenith distance ZS.	Hour angle QA, + toward the west. Declination AS, + above the equator; or polar distance PS.
	The declination and right ascension of stars do not change.	The altitude and azimuth change continually and not uniformly.	The hour angle increases uniformly with the time.

N and M are the north and the south point, respectively; $V Q V'$ is the equator; P, the north pole; and S, any star; $Y X B C$ is the path followed by the center of the sun as it moves over the celestial sphere; hence, X is the vernal equinox (Art. 39). Referring to Fig. 4, the three systems of locating the body S on the celestial sphere may be tabulated as shown on the opposite page.

NOTE.—Before making observations in the field, the student should provide himself with a copy of The American Ephemeris and Nautical Almanac. This book is published yearly by authority of Congress. It contains the positions of the principal stars and of the sun, moon, and planets for every night of the year, and is indispensable to the geodetist and practical astronomer. It can be obtained from the Navy Department, Washington, D. C., for $1. In ordering this book, be careful to state the year desired, since the Ephemeris is of value for only a single year. For this reason also, the student will probably prefer not to buy a copy until he actually begins observations in the field. Specimen portions of all tables required in the solution of the examples in this Section are printed at the end of the Section. By means of these, the student can thoroughly learn the nature and use of the Ephemeris without buying a copy until he needs it in his practical work.

EXAMPLES FOR PRACTICE

1. What is the zenith distance of the north pole in latitude $+30°$?

Ans. $60°$

2. What is the azimuth of: (*a*) the north point? (*b*) the south point? (*c*) the east point?

$$\text{Ans.}\begin{cases}(a)\ 180°\\(b)\ 0°\\(c)\ 270°\end{cases}$$

3. The latitude of Philadelphia, Pa., is $+39° 58' 02''$. (*a*) What is the declination of a star that passes directly overhead at Philadelphia? (*b*) What is the zenith distance of Polaris at Philadelphia when Polaris is on the meridian, the declination of Polaris being $+88° 47'$?

$$\text{Ans.}\begin{cases}(a)\ +39° 58' 02''\\(b)\ 48° 48' 58''\end{cases}$$

4. What is the hour angle: (*a*) of the zenith? (*b*) of the sun at noon? (*c*) of the sun at 8 o'clock in the morning? (*d*) of the sun at midnight?

$$\text{Ans.}\begin{cases}(a)\ 0°\\(b)\ 0°\\(c)\ -4^h \text{ or } -60°\\(d)\ 12^h \text{ or } 180°\end{cases}$$

TIME

SIDEREAL TIME

67. Clocks throughout the world are regulated by comparing them, directly or indirectly, with the clocks of the great national observatories; and these observatory clocks are regulated by means of astronomical observations. To the astronomer, therefore, belongs the duty of the regulation and measurement of time; and this is one of the most important problems of practical astronomy.

The celestial sphere, which turns with an absolutely uniform motion about its axis, is itself a great clock. It carries the stars one after another across the meridian, and if we could select convenient stars on the equator distant 1 hour, or 15°, from one another, we might number them 1 hour, 2 hours, etc., and read the time from the celestial sphere exactly as from a clock on which the dial revolved and the hour hand (or meridian) remained motionless. It is more convenient, however, to use one single point of the celestial sphere, and for this purpose the vernal equinox is selected (Art. 39). When this point is on the meridian, the time is said to be 0 hr. 0 min. 0 sec. When it has moved on from the meridian 1 hour, or 15°, the time is 1 o'clock, and so on. Time so estimated is called **sidereal time**, and the interval of time occupied by the celestial sphere in completing one revolution on its axis is called a **sidereal day.**

68. The passage of a celestial body across the celestial meridian is called its **transit,** or **culmination.** During one complete revolution of the celestial sphere every celestial body crosses the meridian twice. The passage of a body across that branch of the meridian that contains the observer's zenith is called the **upper transit,** or **upper culmination;**

the passage across that branch of the meridian that contains the observer's nadir is called the **lower transit, or lower culmination.**

A **sidereal day** is the interval between two successive upper transits of the vernal equinox, and begins when the vernal equinox is on the meridian.

69. From Art. **68**, it follows that the sidereal time is the hour angle of the vernal equinox. The sidereal clock used in observatories shows sidereal time, provided that it is perfectly regulated. The hands point to $0^h\ 0^m\ 0^s$ when the vernal equinox is on the meridian, and the hours are reckoned from 0^h up to 24^h, when the vernal equinox is again on the meridian. In Fig. 4, the sidereal time is measured by the arc XQ of the equator, or by the hour angle XPQ.

70. Suppose that, in Fig. 4, we had a star in transit, that is, on the meridian between P and M; the right ascension of this star would be the arc XQ (Art. **41**). Hence, the right ascension of a star, when expressed in time, is equal to the sidereal time of the star's transit.

Since the arc XQ is the right ascension of the meridian, it follows that the sidereal time is equal to the right ascension of the meridian.

71. For any star S, Fig. 4, not on the meridian, $QX = QA + AX$; that is, sidereal time = star's hour angle + star's right ascension. Let

$$\theta = \text{sidereal time;}$$
$$t = \text{hour angle;}$$
$$\alpha = \text{right ascension.}$$

Then,
$$\theta = t + \alpha$$

In applying this formula, the algebraic signs of the different quantities should be carefully observed. Since θ expresses time, the hour angle t and the right ascension α should be expressed in time measure. When the hour angle of a heavenly body is reckoned toward the east, it is negative.

EXAMPLE 1.—The hour angle of Sirius on December 25, 1903, at Washington was observed to be $+ 2^h\ 7^m\ 18.1^s$. The right ascension of Sirius, as found from the American Ephemeris (Art. 89), was

$6^h\ 40^m\ 56.4^s$. What was the sidereal time at which the observation was made?

SOLUTION.—
$$\begin{aligned} t &= +2^h\ \ 7^m\ 18.1^s \\ a &= +6\ \ 40\ \ 56.4 \\ \hline \theta &= +8^h\ 48^m\ 14.5^s. \quad \text{Ans.} \end{aligned}$$

EXAMPLE 2.—The star Vega was observed 4 hours to the east of the meridian at Washington on May 20, 1903. The instant of the observation as shown by the sidereal clock was $14^h\ 33^m\ 58.9^s$. Was the clock fast or slow, and how much?

SOLUTION.—Since the star was east of the meridian, t is $-$:

$$t = -\ \ 4^h\ \ 0^m\ \ 0^s$$

From Ephemeris (Art. 89), $a = +18\ \ 33\ \ 41.6$

$$\theta = \quad 14^h\ 33^m\ 41.6^s$$

Hence, the clock at the time of this observation was 17.3 sec. fast. Ans.

APPARENT AND MEAN SOLAR TIME

72. The hour angle of the sun, instead of the hour angle of the vernal equinox, may be employed to determine time. The center of the sun crosses the upper branch of the meridian at **apparent noon**; therefore, the **apparent solar time** at any instant is simply the hour angle of the center of the sun at that instant.

73. An **apparent solar day** is the interval between two successive apparent noons.

74. The sun, unlike the vernal equinox and the stars, is not a fixed point on the celestial sphere. It is continually moving around the heavens toward the east, completely circling the sky in 1 year. In this motion, the sun's right ascension is constantly changing. Hence, the apparent solar day is not of the same length as the sidereal day; nor are all apparent solar days of equal duration. The apparent solar day is longer than the sidereal day by the amount of the sun's daily increase in right ascension.

75. Disadvantage of Sidereal Time.—The sidereal time of apparent noon on any day is equal to the sun's right ascension on that day, and, consequently, it gets later by 24 hours during the year. Thus, the sidereal time

of apparent noon on March 21 is 0^h; on June 21, 6^h; on September 23, 12^h; on December 22, 18^h. It is seen that sidereal time bears no simple relation to the phenomena of day and night, and is therefore unsuitable for every-day use.

76. Disadvantage of Apparent Solar Time.—All apparent solar days are not of equal duration, because the sun in its journey around the sky moves faster at some times than it does at others. They cannot therefore be measured by a clock whose rate is uniform, and for this reason apparent solar time is unsatisfactory for scientific and practical purposes.

77. Mean Time.—Another kind of time, called **mean time,** is generally used for practical purposes. It is defined by reference to what is called the **mean sun.** The mean sun is not a body of any kind, but merely a point that is imagined to move with a uniform speed around the celestial equator completing the entire circuit in the same time that the true sun does. Sometimes the mean sun is ahead of the true sun, and sometimes behind it.

Mean noon is the time of the mean sun's upper transit.

A **mean solar day** is the interval between two successive mean noons. **Mean solar time, or mean time,** is measured by the hour angle of the mean sun. It is the time shown by clocks, and is now used for all practical and scientific purposes, except in some kinds of astronomical work.

78. Astronomical and Civil Time.—When mean time is employed in astronomical work, it is called **astronomical mean time,** and is reckoned continuously up to 24 hours, the astronomical day beginning at mean noon. When mean time is employed in the ordinary affairs of life, it is called **civil time,** and the **civil day** begins at midnight, 12 hours earlier than the astronomical day. Thus, we have the following rules:

Rule I.—*To convert civil time into astronomical time: if the civil time is marked A. M., take 1 from the day and add 12 to the hours; if marked P. M., simply drop the letters P. M.*

Rule II.—*To convert astronomical time into civil time: if the astronomical time is less than 12 hours, simply write P. M. after it; if greater than 12 hours, subtract 12 hours from it, mark the result A. M., and add 1 to the date.*

EXAMPLE 1.—To change January 3, 23^h astronomical time to civil time.

SOLUTION.—According to rule II, the result is, January 4, 11 A. M., civil time.

EXAMPLE 2.—To change June 7, 9 A. M. into astronomical time.

SOLUTION.—According to rule I, the result is, June 6, 21^h astronomical time.

79. Standard Time.—The United States, which lies between longitudes 65° and 125° west of Greenwich, is divided into four **time sections**, in each of which the time used for ordinary purposes is the mean local time of places lying on the meridian passing near the center of the section. These times are called **standard times.** The meridians adopted for this purpose are the 75th, the 90th, the 105th, and the 120th. It will be noticed that these meridians differ by 15°, or 1 hour. The time shown by ordinary clocks and watches at places within $7\frac{1}{2}°$ on either side of one of these meridians is not exactly local time for those places; it is local time only for places lying exactly on that meridian. To find the local time at any given place, it is necessary to subtract, algebraically, from the standard time the difference between the longitude of the place and that of the standard-time meridian. This is a very important fact, and should be constantly borne in mind. Thus, if the standard 75th-meridian time at a place whose longitude is 78° ($= 5^h\,12^m$) is $9^h\,13^m$, the local time is $9^h\,13^m - (5^h\,12^m - 5^h) = 9^h\,01^m$. (See also *Transit Surveying*, Part 2.)

Standard times are called by the following names: 75th-meridian time is called **eastern time**; 90th-meridian time is called **central time**; 105th-meridian time is called **mountain time**; 120th-meridian time is called **Pacific time.**

80. The **equation of time** is the amount that must be added algebraically to the apparent solar time to obtain the corresponding mean time. We have, therefore,

$$(\text{mean time}) = (\text{apparent time}) + (\text{equation of time})$$

It is to be noted that the equation of time is not an equation in the ordinary sense of the word, but simply a quantity. The value of the equation of time is given in the American Ephemeris for each day of the year.

CONVERSION OF TIME

81. When observations are made on stars for the determination of time, it is the sidereal time that is obtained. Though time may be determined more accurately in this way than in any other, it is the mean solar time that is in common use, and hence it is important that one should know the method of changing the time shown by a sidereal clock into mean solar time. On the other hand, when the sun is observed in the field, it is the apparent solar time that is obtained directly from the observation, and from this the mean solar time is obtained by simply adding, algebraically, the equation of time. For many kinds of observations it is absolutely necessary that the sidereal time be known.

82. The **civil local time** of any place on the earth's surface, at any instant, is the time elapsed since the mean sun's last transit, either upper or lower, over the meridian of that place. The 12 hours elapsed between the mean sun's lower and upper transit are A. M. time; the other 12, P. M. time.

83. The **astronomical local time** of any place on the earth's surface, at any instant, is the time elapsed since the mean sun's upper transit over the meridian of that place.

84. To Change a Mean Solar Interval Into Its Equivalent Sidereal Interval.—A mean solar day is longer than a sidereal day by 3 sidereal minutes and 56.555 sidereal seconds. That is, an interval of 24 hours, mean solar time, is equivalent to $24^h\ 3^m\ 56.555^s$, sidereal time.

Mean solar time is reduced to sidereal time by means of Table III of the Ephemeris. This table, a part of which is given at the end of this Section (Table II), contains the

amount to be added to any number of mean solar hours, minutes, and seconds in order to obtain the corresponding number of sidereal hours, minutes, and seconds. The numbers at the heads of the columns express mean solar hours, and those in the column at the extreme left of the page, mean solar minutes. The correction corresponding to any given number of mean solar hours and minutes is found in the column headed by the given number of hours, and in the same horizontal line as the given number of minutes in the left-hand column. The part of the correction corresponding to the mean solar seconds in the given interval is found in the column headed For Seconds at the right of the page. The two numbers taken from the table must be added together, and their sum added to the given number of mean solar hours, minutes, and seconds. The result will be the corresponding number of sidereal hours, minutes, and seconds.

EXAMPLE.—How many sidereal hours, minutes, and seconds are there in the mean solar interval $2^h\ 4^m\ 6.5^s$?

SOLUTION.—From Table II, looking in the column headed 2^h and in the horizontal row containing 4^m, we find

Correction corresponding to $2^h\ 4^m$	$+0^m\ 20.370^s$
From the column headed For Seconds, we find for 6.5^s	$+.017$
Total correction	$+0^m\ 20.387^s$
Mean solar interval	2 4 6.500
Required sidereal interval	$2^h\ 4^m\ 26.887^s$ Ans.

EXAMPLES FOR PRACTICE

Change the following mean solar hours, minutes, and seconds into sidereal hours, minutes, and seconds:

(a) $0^h\ 2^m\ 10^s$.
(b) $2^h\ 10^m\ 2^s$.
(c) $2^h\ 1^m\ 1.4^s$.
(d) $1^h\ 3^m\ 2.5^s$.

Ans. (a) $0^h\ 2^m\ 10.356^s$
(b) $2^h\ 10^m\ 23.361^s$
(c) $2^h\ 1^m\ 21.281^s$
(d) $1^h\ 3^m\ 12.856^s$

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85. To Change a Sidereal Interval Into Its Equivalent Mean Solar Interval.—Sidereal time is converted into mean solar time by means of Table II of the Ephemeris. This table, a part of which is given at the end of

this Section (Table III), is used exactly as the preceding, except that the corrections taken from it are to be subtracted from the given sidereal hours, minutes, and seconds, since any interval contains fewer mean solar than sidereal units.

EXAMPLE.—A sidereal interval contains $2^h\ 4^m\ 6.8^s$. To find its value expressed in mean solar hours, minutes, and seconds.

SOLUTION.—From Table III, we find

For $2^h\ 4^m$	$-0^m\ 20.314^s$
For 6.8^s	$-.018$
Total correction	$-0^m\ 20.332$
Sidereal interval	2 4 6.800
Required mean solar interval	$2^h\ 3^m\ 46.468^s$ Ans.

EXAMPLES FOR PRACTICE

Change the following sidereal hours, minutes, and seconds into mean solar hours, minutes, and seconds:

(*a*) $2^h\ 5^m\ 2^s$.	Ans.	(*a*) $2^h\ 4^m\ 41.517^s$
(*b*) $1^h\ 1^m\ 9^s$.		(*b*) $1^h\ 0^m\ 58.982^s$
(*c*) $2^h\ 10^m\ 10^s$.		(*c*) $2^h\ 9^m\ 48.676^s$
(*d*) $0^h\ 9^m\ 2.24^s$.		(*d*) $0^h\ 9^m\ 0.760^s$

86. The Sidereal Time of Mean Noon.—The sidereal time at any instant is equal to the right ascension of the meridian (Art. 70). Mean noon is the time of the mean sun's upper transit (Art. 77). Therefore, the sidereal time at the instant that the center of the mean sun is on the meridian, or, in other words, the sidereal time of mean noon, is equal to the right ascension of the center of the mean sun at that instant. The sidereal time of mean noon is given in the Ephemeris for every day, the quantity there tabulated being the value of the right ascension of the mean sun at the instant that it crosses the meridian of Washington. (A part of this table will be found at the end of this Section, Table IV.) When the sun is on the meridian of a place west of the Washington observatory, the corresponding Washington time will be a number of hours, minutes, and seconds after noon exactly equal to the difference between the longitude of that place and that of the Washington observatory. In other words, if d is the longitude (west of Washington) of a place, the mean sun will occupy d hours

(minutes and seconds included) in passing from the Washington meridian to the meridian of the place in question. During these d hours, the mean sun's right ascension is increasing uniformly, so that at a station whose longitude is d the right ascension of the mean sun, or, what is the same thing, the sidereal time of mean noon, is greater than the Washington sidereal time of mean noon. The difference is simply the amount by which the right ascension of the mean sun has increased during d hours. This increase may be found from Table III of the Ephemeris (see Table II at the end of this Section). Hence, the following rule to find the sidereal time of mean noon at any place whose longitude *west* of Washington is d, or whose longitude *east* of Washington is $-d$:

Rule.—*Take the sidereal time of mean noon at Washington from the Ephemeris (or Table IV of this Section), and add to it the correction corresponding to d hours, minutes, and seconds taken from Table III of the Ephemeris (or Table II of this Section), if d is +; if d is −, subtract this correction.*

EXAMPLE.—To find the sidereal time of mean noon on January 5, 1903, at an observatory whose longitude is $-2^h\ 10^m\ 8.5^s$.

SOLUTION.—From Table IV, we find

Sidereal time of mean noon at Washington, January 5, 1903, ...	$18^h\ 56^m\ 27.800^s$
From Table II, correction for $-2^h\ 10^m$ . . .	-21.356
Correction for -8.5^s	$-.024$
Hence, the sidereal time of mean noon is . .	$18^h\ 56^m\ \ 6.420^s$ Ans.

The corrections are subtracted, since d is −.

87. Conversion Rules.—Rules for finding mean solar time from sidereal time, and conversely, may now be stated.

Rule I.—*To change sidereal time into mean solar time: from the given sidereal time subtract the sidereal time of the preceding local mean noon (Art. 86); change the remainder, which is the sidereal interval of time elapsed since local mean noon, into mean solar time (Art. 85).*

Rule II.—*To change mean solar time into sidereal time: change the mean solar interval of time elapsed since the*

preceding local mean noon into sidereal time (*Art. 84*), *and add the result to the sidereal time of local mean noon* (*Art. 86*).

EXAMPLE 1.—The sidereal time on the afternoon of January 5, 1903, at a station whose longitude is $+1^h\ 10^m$, was found to be $20^h\ 58^m\ 40^s$. To find the corresponding mean solar time.

SOLUTION.—Here rule I is to be applied.

From Table IV, sidereal time of Washington, mean noon, January 5, 1903	$18^h\ 56^m\ 27.80^s$
From Table II, correction for d	$+11.499$
Hence, sidereal time of mean noon at the station	18 56 39.299
Observed sidereal time	20 58 40.000
Sidereal interval past mean noon	$2^h\ 2^m\ 0.701^s$
Correction to reduce sidereal to mean solar interval, Table III	-19.987
The desired mean solar time is	$2^h\ 1^m\ 40.714^s$ Ans.

EXAMPLE 2.—At a station whose longitude is $+1^h\ 10^m$, the mean solar time on January 5, 1903, was observed to be $2^h\ 1^m\ 0.876^s$, P. M. To find the corresponding sidereal time.

SOLUTION.—Here rule II will be applied.

Mean solar interval since preceding mean noon	$2^h\ 1^m\ 0.876^s$
Correction to reduce mean solar to sidereal interval, Table II	$+19.880$
Sidereal interval since preceding mean noon	$2^h\ 1^m\ 20.756^s$
Sidereal time of mean noon on January 5, 1903, at a longitude of $1^h\ 10^m$, as in example 1	18 56 39.299
Sidereal time	$20^h\ 58^m\ 0.055^s$ Ans.

EXAMPLES FOR PRACTICE

1. At a station whose longitude is $+2^h\ 10^m$, the sidereal time on January 2, 1903, was $19^h\ 45^m$. What was the corresponding mean solar time? Ans. $0^h\ 59^m\ 50.692^s$ P. M.

2. Find the sidereal time corresponding to the instant of 5 minutes past noon, on January 6, 1903, at a station whose longitude is $-1^h\ 1^m\ 10^s$. Ans. $19^h\ 5^m\ 15.123^s$

3. What is the sidereal time corresponding to the mean time $2^h\ 8^m\ 5^s$ P. M. on January 10, 1903, at a station whose longitude is $+7^m\ 4^s$? Ans. $21^h\ 24^m\ 37.782^s$

THE AMERICAN EPHEMERIS

88. Explanation.—The book to be relied on for the fundamental positions of all the heavenly bodies observed is The American Ephemeris and Nautical Almanac, which is published yearly by the United States government. From innumerable observations, the exact nature of the motions of the sun, moon, and planets across the sky is ascertained, and the right ascensions and declinations of these bodies, as well as those of the fixed stars, are predicted for every night of the year, and published in the above work for the use of mariners and astronomers. For the determination of latitude, longitude, and time, and, in short, for any of the observations described in the following articles, this work is indispensable. It is divided into four parts, with an appendix and tables.

89. As all portions of the Ephemeris give the positions of the heavenly bodies at various Washington mean solar times, it is necessary, in order to make use of it, to know how to find the Washington time corresponding to the local time at any place of observation. This is done by adding, algebraically, to the local time, the longitude of the place, counted from Washington.

EXAMPLE.—When it is 8 P. M. in Paris, what is the Washington time, the longitude of Paris being $-5^h\ 18^m\ 36.75^s$?

SOLUTION.—

Local time	$8^h\ 0^m\ 0.00^s$
Longitude of Paris	$-5\ 18\ 36.75$
Corresponding Washington time . . .	$2^h\ 41^m\ 23.25^s$ P. M. Ans.

EXAMPLES FOR PRACTICE

1. The longitude of Cairo, Egypt, is $-7^h\ 13^m\ 24.69^s$. When it is 6 A. M., January 10, at Cairo, what is the time at Washington?
Ans. $10^h\ 46^m\ 35.31^s$ P. M., January 9

2. Find the Washington time of Philadelphia noon, the longitude of Philadelphia being $-7^m\ 37.27^s$. Ans. $11^h\ 52^m\ 22.73^s$ A. M.

3. Find the Washington time corresponding to 4 P. M. at Rome, the longitude of Rome being $-5^h\ 58^m\ 5.25^s$. Ans. $10^h\ 1^m\ 54.75^s$ A. M.

4. When it is 11 A. M. at San Francisco, what is the Washington time, the longitude of San Francisco being $+3^h\ 1^m\ 27.08^s$?
Ans. $2^h\ 1^m\ 27.08^s$ P. M.

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90. To Find the Right Ascension and Declination of a Star From the Ephemeris.—*First method* (approximate).—Look for the name of the star in the first column of Table V of this Section, or of the more complete table found in the Ephemeris, from which Table V is taken. The star's right ascension and declination for the beginning of the year will be found given opposite the name. For example, the right ascension and declination of Polaris are found to be $1^h\ 23^m\ 49.77^s$ and $+88°\ 47'\ 22.84''$, respectively.

This method is sufficiently accurate for nearly all observations made with the engineers' transit.

Second method.—As stated in Art. **30**, the stars are nearly fixed on the celestial sphere, and their right ascensions and declinations do not change materially from year to year. This is nearly the case, yet their positions undergo certain very minute changes, the amounts of which are indicated in the fourth and the sixth column of Table V. Thus, the right ascensions of most of the stars of the table increase about 3^s during the year, and the declinations increase about $20''$.

If it is desired to know the position of a star with great accuracy, the tables of the Ephemeris similar to Table VI, of this Section, but more complete, may be used. This table gives the positions of the stars for successive astronomical dates (Art. **78**). The times are Washington mean solar times; hence the following rule:

Rule.—*To find the right ascension and declination of a star for any given instant at any place, change the civil date to astronomical date, and the resulting local time to Washington*

time (Art. 89). Convert the resulting hours, minutes, and seconds into decimals of a day, and take from Table VI, or from the Ephemeris, the corresponding value of the right ascension and declination.

EXAMPLE.—To find the right ascension and declination of Polaris at 11 P. M., January 4, 1903, San Francisco mean time, the longitude of San Francisco being $3^h\ 1^m$ west of the Washington meridian.

SOLUTION.—Jan. 4, 11 P. M., is	Jan. 4, $11^h\ 0^m$	astronomical time
Longitude of San Francisco . .	$+\ 3\ \ 1$	(Art. 78)
Corresponding Washington time	Jan. 4, $14^h\ 1^m$	= Jan. 4.58

From Table VI, the right ascension and declination of Polaris corresponding to January 4.58 are found to be,

Right ascension, $1^h\ 24^m\ 30.05^s + \frac{28}{100} \times (-1.01^s) = 1^h\ 24^m\ 29.77^s$

Declination, $+88°\ 47'\ 42.4'' + \frac{28}{100} \times (+0.1'') = +88°\ 47'\ 42.4''$

Ans.

EXAMPLE FOR PRACTICE

The longitude of Denver, Colo., is $+1^h\ 52^m$. Find the right ascensions and declinations of the following stars at the Denver mean times specified (see Art. 77): (*a*) of Polaris, at noon, January 4, 1903. (*b*) of Vega, at 9 P. M., February 1, 1903.

Ans. { (*a*) $1^h\ 24^m\ 30.28^s$; $+88°\ 47'\ 42.4''$
(*b*) $18^h\ 33^m\ 38.35^s$; $+38°\ 41'\ 34.1''$ }

91. The Solar Ephemeris.—This part of the Ephemeris, the first few lines of which are given as Table IV at the end of this Section, gives the right ascension and declination of the mean sun for every day in the year, at the instant of Washington mean noon, and also the hourly increase or decrease in the sun's right ascension and declination. It also contains the equation of time, the apparent angular semi-diameter of the sun, and the sidereal time of mean noon at Washington. All these quantities will be required in the calculations to be explained in this Section.

92. To Find the Right Ascension and Declination of the Sun at Any Instant.

Rule.—*Change the local time to Washington time (Art. 89). Take from the table the right ascension and declination corresponding to the preceding Washington mean noon, and add algebraically to these quantities the product of the corresponding*

hourly motions by the number of hours elapsed since Washington mean noon.

EXAMPLE 1.—What is the right ascension and declination of the sun at 9 A. M., January 3, 1903, Ann Arbor mean time, the longitude of Ann Arbor being $+26^m\ 39.41^s$?

SOLUTION.—

Astronomical local time	Jan. 2, $21^h\ 0^m\ 0.00^s$
Longitude of Ann Arbor	$+26\ 39.41$
Washington mean time	Jan. 2, $21^h\ 26^m\ 39.41^s$ = Jan. 2, 21.444^h

Right ascension of sun at Washington mean noon, January 2	$18^h\ 48^m\ 30.52^s$
Increase of right ascension during 21.444 hr, = hourly motion (11.037^s) × 21.444 . . .	$+3\ 56.68$
Hence, the desired right ascension	$18^h\ 52^m\ 27.20^s$ Ans.
Declination of sun at Washington mean noon, January 2	$-22°\ 58'\ 51.00''$
Increase of declination during 21.444 hr. = hourly motion (12.78″) × 21.444	$+4\ 34.05$
Hence, the desired declination is	$-22°\ 54'\ 16.95''$ Ans.

EXAMPLE 2.—What is the right ascension and declination of the sun when it has an hour angle of 1 hour at an observatory near Philadelphia, January 5, 1903, the longitude of this observatory being $-7^m\ 37.27^s$?

SOLUTION.—The local time is 1^h after apparent noon (Art. 72).

Local time after apparent noon . . .	$1^h\ 0^m\ 0.00^s$
Longitude of Philadelphia	$-7\ 37.27$
Washington time after apparent noon	$0^h\ 52^m\ 22.73^s = .873^h$

Right ascension of sun for Washington apparent noon, January 5 (Table IV)	$19^h\ 1^m\ 44.41^s$
Increase of the right ascension = $+10.987^s$ × .873	$+0\ \ 9.59$
Hence, the desired right ascension	$19^h\ 1^m\ 54.00^s$ Ans.
Declination of sun for Washington apparent noon, January 5 (Table IV)	$-22°\ 41'\ 26.5''$
Increase of the declination, +16.18″ × 0.873	$+14.1$
Hence, the desired declination	$-22°\ 41'\ 12.4''$ Ans.

Example 2 may also be solved by changing the apparent time into mean time (Art. 80), and proceeding as in example 1. Precisely the same results will be obtained, but the solution will involve an unnecessary amount of labor.

EXAMPLE FOR PRACTICE

The longitude of Chicago is $+42^m\ 11^s$. Find the right ascension and declination of the sun at the following Chicago times: (*a*) January 2, $11^h\ 18^m\ 49^s$ A. M. (*b*) January 5, apparent noon.

Ans. $\begin{cases} (a)\ 18^h\ 48^m\ 30.52^s;\ -22°\ 58'\ 51.0'' \\ (b)\ 19^h\ 1^m\ 52.13^s;\ -22°\ 41'\ 15.1'' \end{cases}$

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93. To Find the Equation of Time at Any Instant. This may be taken directly from Table IV, after reducing local time to Washington time.

Rule.—*Find the difference between the values of the equation of time corresponding to the preceding and the following Washington noon, and multiply it by the decimal part of a day elapsed since Washington noon; add the result algebraically to the equation of time corresponding to the preceding Washington noon.*

The difference between two successive values of the equation of time is the daily change; it is additive if these values are increasing, and subtractive if they are decreasing.

EXAMPLE.—To find the value of the equation of time at 9 A. M., January 3, Ann Arbor mean time, the longitude of Ann Arbor being $+26^m\ 39.41^s$.

SOLUTION.—

Ann Arbor local time	Jan. 2, $21^h\ 0^m\ 0.00^s$
Longitude of Ann Arbor	$+26\ \ 39.41$
Washington mean time	Jan. 2, $21^h\ 26^m\ 39.41^s$
	Jan. 2, $+0.894$ da.
Equation of time for noon, Jan. 2 . .	$+3^m\ 52.48^s$
Equation of time for noon, Jan. 3 . .	$+4\ \ 20.63$
Change in equation of time for 1 da.	$+28.15^s$
Total change since Washington noon $= +28.15^s \times 0.894$	$+25.17^s$
	$+3\ \ 52.48$
Hence, the desired equation of time	$+4^m\ 17.65^s$ Ans.

EXAMPLES FOR PRACTICE

The longitude of Cincinnati is $+29^m\ 26^s$. Find the values of the equation of time at the following Cincinnati mean times:

(*a*) January 2, 1903, 9 A. M.	Ans.	(*a*) $+3^m\ 49.49^s$
(*b*) January 5, noon.		(*b*) $+5^m\ 16.29^s$
(*c*) January 4, 6 P. M.		(*c*) $+4^m\ 55.78^s$

---

94. To Find the Angular Semi-Diameter of the Sun.—This is the angle subtended at the eye of the observer by the sun's radius, and may be taken from the table in exactly the same manner as the equation of time.

Rule.—*Take the value corresponding to the preceding Washington noon and add to it the product of the daily change by the decimal part of a day elapsed since that Washington noon.*

EXAMPLE.—To find the semi-diameter of the sun at 4 P. M., January 1, 1903, local mean time, the longitude of the observer being $-7^m\ 37.27^s$.

SOLUTION.—

Local mean time	Jan. 1, $4^h\ 0^m\ 0.00^s$
Longitude	$-7\ \ 37.27$
Washington mean time	Jan. 1, $3^h\ 52^m\ 22.73^s$
	Jan. 1, +0.161 da.
Semi-diameter, January 1	16′ 17.81″
Semi-diameter, January 2	16′ 17.83″
Daily change	−.02
Increase of semi-diameter since Washington noon $= (-.02'') \times 0.161$	−.00″
	16 17.81
Hence, the desired semi-diameter is	16′ 17.81″

The method of finding the sidereal time of mean noon at any place of observation was explained in Art. 86.

NOTE.—For the purpose of ordinary calculations, the semi-diameter of the sun may be taken from the following short table:

Time of year (approx.) . . .	Jan. 1,	Apr. 1,	July 1,	Oct. 1
Sun's semi-diameter	16′ 18″	16′ 2″	15′ 45″	16′ 2″

EXAMPLES FOR PRACTICE

The longitude of San Francisco is $+3^h\ 1^m\ 27^s$. Find the semidiameter of the sun at the following San Francisco mean times:

(*a*) January 1, 10 P. M.
(*b*) January 5, 6 A. M.
(*c*) January 2, 8 A. M.

Ans. (*a*) 16′ 17.82″; (*b*) 16′ 17.81″; (*c*) 16′ 17.83″

DETERMINATION OF ALTITUDE

95. The **altitude** of a heavenly body is the angle between the plane of the observer's horizon and a line from the observer's station to that body. The instruments most frequently employed for measuring this angle are the sextant and the engineers' transit.

USE OF THE SEXTANT

NOTE.—For a description of the sextant, its theory, adjustments, and uses, see *Hydrographic Surveying*.

96. The Artificial Horizon.—For observing altitudes on land, an artificial horizon similar to the one shown in Fig. 10 must be used. This is a shallow basin cc' about 3 by 5 inches for holding mercury. It is provided with a

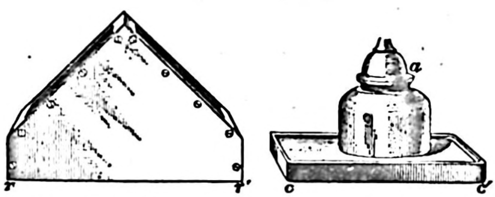

FIG. 10

roof rr' formed of two pieces of plate glass set at right angles to each other in a metal frame, for protecting the mercury from agitation by the wind. The surface of the mercury forms a mirror from which the image of the sun or star is reflected; and as it is perfectly horizontal, the

reflected image will appear at an angular distance below the horizon equal to the altitude of the body itself above the horizon.

If the image of a star reflected from the mirrors of the sextant is brought into contact with the image reflected from the mercury, the angle that will be measured is twice the altitude of the star. This is explained by means of

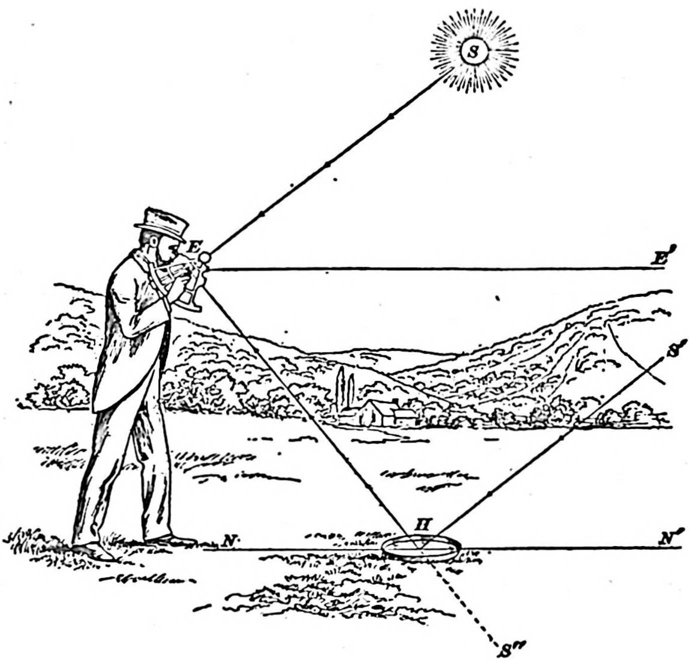

FIG. 11

Fig. 11, where either SEE' or $S'HN'$ may be considered as the altitude of the body, EE' and NN' being horizontal lines, and $S'H$ being the line from H to the star, which line may be considered to be parallel to ES, on account of the remoteness of the star. Now, $S'HS'' = SES''$ is the angle measured, since the object seen at H will appear to be in the direction EHS''. But, from the physical law of

reflection, $S' H N' = E H N = N' H S''$. Hence, the angle measured $S' H S''$ equals twice the altitude $S' H N'$.

In connection with the use of an artificial horizon, it is well to bear in mind that, before any observations are made, the mercury must be freed from the particles of dust and impurities that will generally be found floating on its surface. A good method is to strain the mercury through a piece of chamois skin or through a funnel of paper brought down to a fine point at the end. Another method is to add a small amount of tin-foil to the mercury, when the amalgam that will be formed will rise to the top and may be drawn to one side with a card, leaving the surface entirely free from specks of any kind.

When observing, it will be found much more convenient to sit on a box or a very low chair, or even on the ground, so as to bring the telescope as near to the mercury as possible. An artificial horizon may be formed by pouring oil or syrup into a shallow vessel; but when mercury is available, it is always to be preferred.

97. The Index Error.—The index error should always be determined both before and after any observations with the sextant. At least four pointings should be made, preferably on a fixed star, and the mean of these readings should be taken (see *Hydrographic Surveying*).

When the sun is observed, the index correction must be determined as follows:

Rule.—*Measure the apparent diameter of the sun by bringing the direct and reflected images tangent to each other, and read the vernier; then bring the opposite limbs into the position of tangency and again read the vernier. Prefix to the readings their proper signs, as explained in Hydrographic Surveying, add them together algebraically, and divide the sum by 2. The result will be the index correction.*

More than one pointing is usually made on each limb, and the mean taken.

EXAMPLE.—To determine the index error from the following observations, which were made on the sun in the manner described:

MINUS READINGS	PLUS READINGS
32′ 20″	30′ 60″
32′ 20″	30′ 60″
32′ 25″	30′ 50″
32′ 20″	30′ 50″
129′ 25″	123′ 40″

SOLUTION.—The mean of each series is found by dividing the sum of the four single readings by 4. We thus find:

Mean of negative readings	−32′ 21.2″
Mean of positive readings	+30′ 55.0″
Algebraic sum	−1′ 26.2″
Index correction, ½ (algebraic sum)	−0′ 43.1″

USE OF THE ENGINEERS' TRANSIT

98. Essential Conditions.—The engineers' transit is fully described in *Transit Surveying*, Part 1. If the instrument is provided with a vertical circle, it may be used either with or without an artificial horizon for directly measuring altitudes. The bubbles on the plate must be very carefully adjusted; especially the bubble parallel to the vertical circle, for it is on this bubble that the accuracy of the result wholly depends. The telescope bubble must also be in accurate adjustment, parallel to the line of sight.

99. The Vertical Circle.—The circle should read zero when the line of sight is horizontal, if there is no index error. The reading, if any, of the vertical circle when the plate is leveled and the telescope bubble is brought to the middle of its tube, is the index error. If the vernier on the vertical circle is adjustable, the reading on the limb may be made zero when the line of sight is horizontal, and then no correction for index error will be required.

The adjustment of the telescope bubble, of the plate bubbles, and of the vernier of the vertical circle should always be tested just before and just after any series of observations with the transit. If the plate bubble parallel to the vertical circle, the telescope bubble, and the vernier of the vertical circle have been accurately adjusted, then, whenever these bubbles are brought to the centers of their tubes, the reading on the vertical circle should either be zero or the index

correction previously determined, according as the vernier is or is not adjustable. This test can always be very quickly applied.

In case the vertical limb is a complete circle, the error of adjustment of the plate bubbles and of the vernier can be eliminated by first reading the altitude, then revolving the instrument in azimuth 180°, releveling the instrument (but without readjusting any of the levels), reading the vertical angle again with the telescope in its reversed position, and taking the mean of the two readings. Every altitude should be measured in this way when the vertical circle is complete; no correction for index error is then required.

100. To Measure an Altitude by Using the Artificial Horizon.—When the vertical limb is not a complete circle, the index error can be eliminated by using an artificial or mercury horizon. This must first be put in the proper position with reference to the transit, since, unlike the sextant, the transit cannot be conveniently moved about. To accomplish this, the transit is set up and pointed on the star, and the altitude is read from the vertical circle. The telescope is then depressed through an angle equal to twice the approximate altitude, and sighting through it, the point on the ground is noted at which the intersection of the cross-wires seems to fall. The mercury horizon should be set at that point.

The telescope is then directed to the star whose altitude is required, and the vertical circle is read. A second reading is taken by directing the telescope toward the image reflected in the mercury. One-half of the total angle turned through, or of the sum of the two readings, will be the altitude of the star (Art. 96).

No correction for index error need be applied, since the use of the mercury horizon eliminates the index error. This is the only simple method by which this error can be eliminated when the vertical limb is not a complete circle.

101. Observation of Stars With a Transit.—When a transit is used for observing the stars, it is necessary to

illuminate the cross-wires. The simplest method of doing this is by holding a bull's-eye lantern so as to throw the light down the telescope tube through the objective, care being taken not to obstruct the line of sight. A little practice will enable one to do this very easily: the lantern is held in front and a little to one side of the object end of the telescope with the left hand, and the instrument is manipulated with the right. It is more convenient, however, to have some kind of reflector fitted to the object end of the telescope, so that the lantern may be turned from the eyes of the observer rather than toward them.

A very good reflector may be made from a piece of new tin, cut and bent as in Fig. 12. The straight strip is bent about the object end of the telescope tube, leaving the annular elliptic piece projecting over in front. This is then bent to any desired angle, preferably about 45°, and turned so that the light can be thrown down the tube by illuminating the disk from a convenient position. If the reflecting side of the disk is whitened, the effect is very good. The opening should be about $\frac{3}{4}$ inch or $\frac{7}{8}$ inch in its shorter diameter, the longer diameter being such as to make its normal projection equal to the shorter one. There is, of course, no necessity for limiting the outer edges of the disk.

FIG. 12

CORRECTIONS TO THE MEASURED ALTITUDE

102. It has been stated that to every reading from the circle of either the sextant or the transit instrument, the index correction must be added. This is a purely instrumental error. The apparent altitude of a heavenly body is also always affected by the refraction of the rays of light from the body in passing through the atmosphere. In case the sun or moon is observed, further corrections for semi-diameter and parallax must be applied; while the altitudes of all bodies observed at sea must be corrected for the dip of the horizon. The methods of computing and applying these corrections will now be explained.

REFRACTION

103. A ray of light travels in a straight line so long as its path is in a medium of uniform density; but when it passes obliquely from one medium into another of different density, it undergoes a change of direction at the surface of separation. This change of direction or bending of a ray of light is called **refraction.** Thus, if EE', Fig. 13, represents the surface of the earth on which an observer stands at O, and if the surface EE' is surmounted by an atmosphere $EMNE'$ of uniform density and of a definite height, a ray of light from any celestial body S will be bent downwards on reaching the upper surface MN of the atmosphere. The ray will move along the broken line SAO instead of traveling in a straight path.

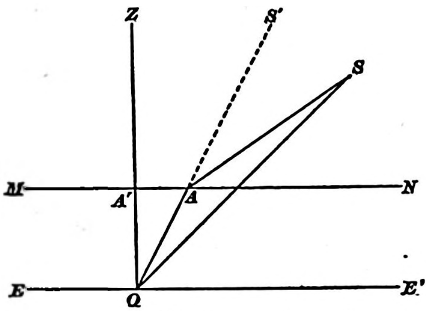

FIG. 13

The apparent position of a body depends on the direction in which its light enters the observer's eye; hence, the celestial body S will appear to be at S' instead of in its true position S. The difference between the direction OS in which the body would be were there no refraction, and the direction OS' in which it appears to be, is the astronomical refraction. It is thus seen that the effect of refraction is to increase the altitude of all heavenly bodies. The altitude SOE' is called the **true altitude**; the altitude $S'OE'$ is called the **apparent altitude.** To find the true altitude when the apparent altitude has been measured, the amount of the refraction SOS' must be subtracted from the apparent altitude $S'OE'$.

This explanation assumes the space above MN in the figure to be entirely empty, and the earth's atmosphere $MNE'E$ to be equally dense throughout. In fact, however, the earth's atmosphere is most dense at the surface of the

earth, and gradually diminishes in density to its exterior boundary. The direction of a ray of light traveling in such medium is constantly changing, and so the path of the ray is a curved line. This curve is represented by line *e d c b a A*, Fig. 14. The ray of light from the star *S* first meets the upper surface of the atmosphere at *e* and is then successively refracted as it passes into layers of greater and greater density, until it finally enters the eye of the observer at *A* in the direction of *A a S'*, making *S'* the apparent position of the star.

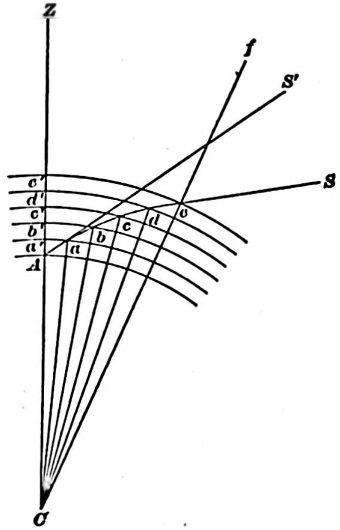

FIG. 14

104. The exact determination of the amount of refraction corresponding to any altitude is a problem that cannot be completely solved, since the refraction depends on the temperature and density of the air, not only at the surface of the earth, but also along the whole path of the ray *A a b c d e*, Fig. 14. Approximate tables may be constructed, however, that will give the amount of the correction within 1 second or less, provided that the body is not too near the horizon. When the altitude of a body is small, the rays of light from it pass nearly along the earth's surface through many hundred miles of comparatively dense air and the refraction cannot be accurately determined by any method. Hence, when the measured altitude of any body is less than 8° or 10°, *the refraction becomes so uncertain that the measurement is of no value for any kind of accurate work.*

Table VII, at the end of this Section, gives the amount of refraction corresponding to different altitudes. It is founded on the investigations of a celebrated German

astronomer named Bessel, and is known as *Bessel's table of refractions.*

105. Correcting a Measured Altitude for Refraction.

Rule.—*Look in Table VII for the refraction corresponding to the measured altitude, and subtract this correction from that altitude.*

EXAMPLE.—The altitude of Sirius was observed to be 18° 04′ 10″. It is required to correct this altitude for refraction.

SOLUTION.—

Observed altitude	18° 04′ 10″
Refraction	−02 53
Corrected or true altitude	18° 01′ 17″ Ans.

EXAMPLES FOR PRACTICE

Correct the following measured altitudes for refraction:

(*a*) 39° 48′ 10″.	Ans.	(*a*) 39° 47′ 02″
(*b*) 15° 10′ 20″.		(*b*) 15° 06′ 52″
(*c*) 22° 11′ 05″		(*c*) 22° 8′ 46″

PARALLAX

106. Geocentric Place.—The positions of all heavenly bodies are referred to the center of the earth. The **geocentric place** of a heavenly body is the position on the celestial sphere that it appears to occupy when viewed from the center of the earth. The right ascensions and declinations of the geocentric places of the sun and moon are published in the American Ephemeris.

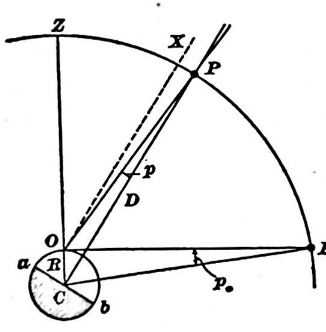

FIG. 15

107. The **parallax** of a heavenly body is the difference in direction of the body as actually observed and the direction that it would have if seen from the earth's center. Thus, in Fig. 15, where the observer is supposed to be at O,

the position of P in the sky (as seen from O) would be marked by the point where OP produced would pierce the celestial sphere. Its position as seen from C would be determined by producing CP. The angle POX formed by OP and a line parallel to CP is the parallax of P for an observer at O.

Since the angle POX equals the angle OPC, the parallax may also be defined as the angular distance between the observer's station and the center of the earth, as seen from the body observed.

108. Correction of Altitude and Zenith Distance for Parallax.—Let A, Fig. 16, be the position of the observer; C, the center of the earth; AH, the horizon; CH', a parallel to AH; Z, the zenith; and M, the position of a heavenly body. Then the angle z_a is the apparent or observed zenith distance of M, while z is its geocentric zenith distance. Likewise, h_a and h are, respectively, the apparent and the geocentric altitude of the body, and p is its parallax. The triangle CAM gives

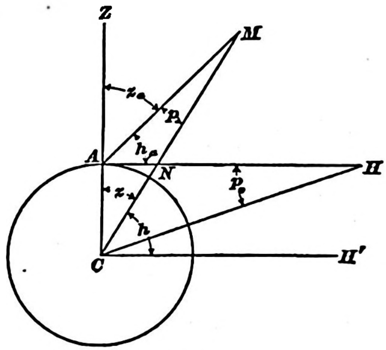

FIG. 16

$$z = z_a - p \qquad (1)$$

That is, the geocentric zenith distance is equal to the observed zenith distance minus the parallax.

The angle MNH, external to the triangle MNA, is equal to h, since NH is parallel to CH'. Therefore,

$$h = h_a + p \qquad (2)$$

That is, the geocentric altitude is equal to the observed altitude plus the parallax.

In the case of the stars, no correction of any kind need be applied for parallax, as the geocentric parallax of the nearest star is less than one-millionth of a second.

109. Formula for Parallax.—Referring to Fig. 16, let the distance CM of the body from the center of the earth be denoted by d, and the radius CA by r. In the triangle CAM, the sides CA and CM, or r and d, are to each other as the sines of the opposite angles p and CAM; but instead of sin CAM, the sine of its supplement z_a may be used. Therefore, $\frac{r}{d} = \frac{\sin p}{\sin z_a}$, and

$$\sin p = \frac{r}{d} \sin z_a \qquad (1)$$

Since $z_a = 90° - h_a$, we have, also, $\sin z_a = \cos h_a$, and, therefore,

$$\sin p = \frac{r}{d} \cos h_a \qquad (2)$$

110. The **horizontal parallax** of a body is the geocentric parallax of the body when the latter is in the horizon. Thus, in Fig. 16, the angle AHC, or p_o, is the horizontal parallax of the body H. The horizontal parallax of the sun may be found tabulated for every tenth day of the year, in the American Ephemeris.

111. Formula for Horizontal Parallax.—When a body is in the horizon, its apparent zenith distance z_a is 90°, and therefore $\sin z_a = 1$. Writing in formula 1, Art. 109, p_o for p and 1 for $\sin z_a$, the following formula for horizontal parallax is obtained:

$$\sin p_o = \frac{r}{d}$$

112. Parallax of the Sun.—Since $\frac{r}{d} = \sin p_o$, formula 2, Art. 109, may be written

$$\sin p = \sin p_o \cos h_a \qquad (1)$$

In the case of the sun, p and p_o are so small that the angles themselves may be used instead of their sines. By making this substitution, formula 1 becomes

$$p = p_o \cos h_a \qquad (2)$$

Table VIII, at the end of this Section, makes the application of formula 2 unnecessary.

EXAMPLE.—The altitude of the sun on May 14, 1903, was observed to be 24° 18′ 20″. It is required to correct this altitude for parallax.

SOLUTION.—(1) *By the formula.* From the Ephemeris, the horizontal parallax on May 14 is found to be +8.70″. Hence,

Parallax = 8.70 cos 24° 18′ = 8.70″ × 0.912 .	+7.93″
Observed altitude	24 18 20.00
Altitude corrected for parallax	24° 18′ 27.93″

(2) *By the table.*

Observed altitude	24° 18′ 20″
Correction for parallax from Table VIII	+8
Corrected altitude	24° 18′ 28″

The table will always be sufficiently accurate to correct altitudes that are measured with the transit or sextant.

EXAMPLES FOR PRACTICE

Correct the following measured altitudes of the sun for parallax:

		Ans.
(*a*)	25° 10′ 0″.	(*a*) 25° 10′ 08″
(*b*)	60° 09′ 10″.	(*b*) 60° 09′ 14″
(*c*)	10° 10′ 5″.	(*c*) 10° 10′ 14″
(*d*)	5° 09′ 10″.	(*d*) 5° 09′ 19″

CORRECTION FOR SEMI-DIAMETER

113. Whenever the altitude of the sun or moon is observed with the sextant, it is either the highest or the lowest point of the disk of the body that is brought into coincidence with its reflection from the mercury. Similarly, when the observations are taken with the transit, the horizontal wire is placed tangent to the upper or lower edge of the apparent disk. Thus, as a result of the observation, the altitude of either the upper or the lower edge is obtained. The observed altitude must be corrected by adding to or subtracting from it the angular semi-diameter of the observed body, according as the lower or the upper edge has been observed (see Art. 94).

CORRECTION (AT SEA) FOR THE DIP OF THE HORIZON

114. In observations of altitude at sea, where the measurement is made from the sea horizon, a correction is needed on account of the fact that this visible horizon does not coincide with the true astronomical horizon, but falls sensibly below it by an amount known as the **dip of the horizon.** The amount of this dip depends on the height of the observer's eye above the sea level.

In Fig. 17, C is the center of the earth, and O the observer, at an elevation h above the earth's (or ocean's) surface at A. The line OH is horizontal, while the tangent line OB corresponds to the sea horizon. The angle D is the *dip*.

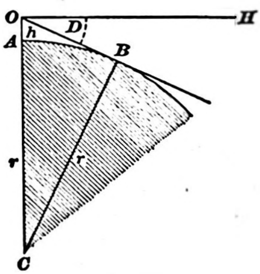

FIG. 17

Table IX, at the end of this Section, gives the correction for dip corresponding to various heights of the observer's eye above the surface of the ocean. These numbers include correction for refraction. The number taken from the table is to be subtracted from the measured altitude. If a table is not available, the correction for dip and refraction may be obtained from the formula

$$D'' = 59\sqrt{h}$$

where D'' = dip (refraction included), in seconds, and
h = height, in feet, of observer's eye above surface of sea.

EXAMPLE.—The altitude of Sirius above the visible sea horizon was observed to be 38° 40′ 10″. The measurement was made from the bridge of a steamer, the eye of the observer being approximately 34 feet above the water level. It is required to correct the altitude for dip.

SOLUTION.—

Measured altitude	38° 40′ 10″
From Table IX, correction for dip corresponding to 34 feet	−5 43
Corrected altitude	38° 34′ 27″

EXAMPLES FOR PRACTICE

1. The altitude of the lower edge of the sun was observed on January 5, 1903; the eye of the observer was 10 feet above the water line; the measured altitude was 20° 10′ 10″. Correct this altitude for semi-diameter and for dip. Ans. 20° 23′ 23″

2. Correct an altitude of 10° measured at a height of 10 feet, for dip. Ans. 9° 56′ 55″

3. Correct an altitude of 20°, measured at a height of 20 feet, for semi-diameter and for dip, the measurement being made on the upper edge of the sun on January 1, 1903. Ans. 19° 39′ 19″

ILLUSTRATIVE EXAMPLES OF THE DETERMINATION OF ALTITUDES

EXAMPLE 1.—At San Francisco, at 11 o'clock A. M. January 4, 1903, the altitude of the upper edge of the sun was observed with a sextant, using an artificial horizon; the circle reading was 46° 20′ 10″. At the same time, readings were taken for index error as follows:

MINUS READINGS	PLUS READINGS
31′ 0″	32′ 10″
31′ 20″	32′ 20″
31′ 10″	32′ 30″

What was the true altitude of the sun's center?

SOLUTION.—The first correction is that for index error.

Mean of minus readings	−31′ 10″
Mean of plus readings	+32 20
Algebraic sum	+1′ 10″
Index correction, ½ (algebraic sum)	+35
Circle reading = double altitude	46 20 10
Corrected double altitude	46° 20′ 45″
Altitude corrected for index error	23 10 22.5
Correction for refraction (Table VII)	−2 13
Correction for parallax (Table VIII)	+8
Final corrected altitude of sun's upper edge	23° 8′ 17.5″

There remains the correction for semi-diameter. We first find the semi-diameter (Art. 94).

Civil local time is January 4, 11 A. M.; astronomical time, Jan. 3	$23^h\ 0^m\ 0.0^s$
Longitude of San Francisco	+3 1 27.1
Washington mean time, Jan. 4	$2^h\ 1^m\ 27.1^s$
	or Jan. 4, .0843 da.

Hence, from Table IV, semi-diameter for January 4, .0843 da. = 16′ 17.8″.

Corrected altitude of sun's upper edge	23° 8′ 17.5″
Correction for semi-diameter	−16 17.8
Final corrected altitude of sun's center	22° 51′ 59.7″
	Ans.

EXAMPLE 2.—The altitude of Vega was observed with a sextant and an artificial horizon; the circle reading was found to be +30° 28′ 40″. Immediately afterwards, readings were made on a star for index error as follows: Minus readings, 40″, 20″, 30″, 30″. To find the true altitude of Vega.

SOLUTION.—When a star is observed, no correction for semi-diameter or parallax need be applied; it is only necessary to correct the observation for index error and for refraction.

Observed double altitude	30° 28′ 40″
Correction for index error = mean of above four readings	−30
Corrected double altitude	30° 28′ 10″
Single altitude	15° 14′ 5″
Correction for refraction (Table VII)	−3 27
Final corrected altitude of star	15° 10′ 38″

EXAMPLES FOR PRACTICE

1. The altitude of a star was observed with a transit having an incomplete vertical circle; the correction for index error was −1′; the circle reading was 30° 10′ 30″. Find the true altitude.

Ans. 30° 7′ 52″

2. The altitude of a star was measured with a transit as explained in Art. 99; the measured altitude was 60° 12′ 10″. Find the true altitude.

Ans. 60° 11′ 37″

TABLE I

CONVERSION OF ARC AND TIME

D.	H.M.	D.	H.M.	D.	H.M.	D.	H.M.	D.	H.M.	D.	H.M.
M.	M.S.	M.	M.S.	M.	M.S.	M.	M.S.	M.	M.S.	M.	M.S.
1	0 4	61	4 4	121	8 4	181	12 4	241	16 4	301	20 4
2	0 8	62	4 8	122	8 8	182	12 8	242	16 8	302	20 8
3	0 12	63	4 12	123	8 12	183	12 12	243	16 12	303	20 12
4	0 16	64	4 16	124	8 16	184	12 16	244	16 16	304	20 16
5	0 20	65	4 20	125	8 20	185	12 20	245	16 20	305	20 20
6	0 24	66	4 24	126	8 24	186	12 24	246	16 24	306	20 24
7	0 28	67	4 28	127	8 28	187	12 28	247	16 28	307	20 28
8	0 32	68	4 32	128	8 32	188	12 32	248	16 32	308	20 32
9	0 36	69	4 36	129	8 36	189	12 36	249	16 36	309	20 36
10	0 40	70	4 40	130	8 40	190	12 40	250	16 40	310	20 40
11	0 44	71	4 44	131	8 44	191	12 44	251	16 44	311	20 44
12	0 48	72	4 48	132	8 48	192	12 48	252	16 48	312	20 48
13	0 52	73	4 52	133	8 52	193	12 52	253	16 52	313	20 52
14	0 56	74	4 56	134	8 56	194	12 56	254	16 56	314	20 56
15	1 0	75	5 0	135	9 0	195	13 0	255	17 0	315	21 0
16	1 4	76	5 4	136	9 4	196	13 4	256	17 4	316	21 4
17	1 8	77	5 8	137	9 8	197	13 8	257	17 8	317	21 8
18	1 12	78	5 12	138	9 12	198	13 12	258	17 12	318	21 12
19	1 16	79	5 16	139	9 16	199	13 16	259	17 16	319	21 16
20	1 20	80	5 20	140	9 20	200	13 20	260	17 20	320	21 20
21	1 24	81	5 24	141	9 24	201	13 24	261	17 24	321	21 24
22	1 28	82	5 28	142	9 28	202	13 28	262	17 28	322	21 28
23	1 32	83	5 32	143	9 32	203	13 32	263	17 32	323	21 32
24	1 36	84	5 36	144	9 36	204	13 36	264	17 36	324	21 36
25	1 40	85	5 40	145	9 40	205	13 40	265	17 40	325	21 40
26	1 44	86	5 44	146	9 44	206	13 44	266	17 44	326	21 44
27	1 48	87	5 48	147	9 48	207	13 48	267	17 48	327	21 48
28	1 52	88	5 52	148	9 52	208	13 52	268	17 52	328	21 52
29	1 56	89	5 56	149	9 56	209	13 56	269	17 56	329	21 56
30	2 0	90	6 0	150	10 0	210	14 0	270	18 0	330	22 0
31	2 4	91	6 4	151	10 4	211	14 4	271	18 4	331	22 4
32	2 8	92	6 8	152	10 8	212	14 8	272	18 8	332	22 8
33	2 12	93	6 12	153	10 12	213	14 12	273	18 12	333	22 12
34	2 16	94	6 16	154	10 16	214	14 16	274	18 16	334	22 16
35	2 20	95	6 20	155	10 20	215	14 20	275	18 20	335	22 20
36	2 24	96	6 24	156	10 24	216	14 24	276	18 24	336	22 24
37	2 28	97	6 28	157	10 28	217	14 28	277	18 28	337	22 28
38	2 32	98	6 32	158	10 32	218	14 32	278	18 32	338	22 32
39	2 36	99	6 36	159	10 36	219	14 36	279	18 36	339	22 36
40	2 40	100	6 40	160	10 40	220	14 40	280	18 40	340	22 40
41	2 44	101	6 44	161	10 44	221	14 44	281	18 44	341	22 44
42	2 48	102	6 48	162	10 48	222	14 48	282	18 48	342	22 48
43	2 52	103	6 52	163	10 52	223	14 52	283	18 52	343	22 52
44	2 56	104	6 56	164	10 56	224	14 56	284	18 56	344	22 56
45	3 0	105	7 0	165	11 0	225	15 0	285	19 0	345	23 0
46	3 4	106	7 4	166	11 4	226	15 4	286	19 4	346	23 4
47	3 8	107	7 8	167	11 8	227	15 8	287	19 8	347	23 8
48	3 12	108	7 12	168	11 12	228	15 12	288	19 12	348	23 12
49	3 16	109	7 16	169	11 16	229	15 16	289	19 16	349	23 16
50	3 20	110	7 20	170	11 20	230	15 20	290	19 20	350	23 20
51	3 24	111	7 24	171	11 24	231	15 24	291	19 24	351	23 24
52	3 28	112	7 28	172	11 28	232	15 28	292	19 28	352	23 28
53	3 32	113	7 32	173	11 32	233	15 32	293	19 32	353	23 32
54	3 36	114	7 36	174	11 36	234	15 36	294	19 36	354	23 36
55	3 40	115	7 40	175	11 40	235	15 40	295	19 40	355	23 40
56	3 44	116	7 44	176	11 44	236	15 44	296	19 44	356	23 44
57	3 48	117	7 48	177	11 48	237	15 48	297	19 48	357	23 48
58	3 52	118	7 52	178	11 52	238	15 52	298	19 52	358	23 52
59	3 56	119	7 56	179	11 56	239	15 56	299	19 56	359	23 56
60	4 0	120	8 0	180	12 0	240	16 0	300	20 0	360	24 0

TABLE II

PART OF TABLE III OF THE AMERICAN NAUTICAL ALMANAC, FOR CHANGING MEAN SOLAR INTO SIDEREAL TIME

(To be added to mean solar interval)

Mean Solar	0^h	1^h	2^h	For Seconds	
m	m s	m s	m s	s	s
0	0 0.000	0 9.856	0 19.713	0	0.000
1	0 0.164	0 10.021	0 19.877	1	0.003
2	0 0.329	0 10.185	0 20.041	2	0.005
3	0 0.493	0 10.349	0 20.206	3	0.008
4	0 0.657	0 10.514	0 20.370	4	0.011
5	0 0.821	0 10.678	0 20.534	5	0.014
6	0 0.986	0 10.842	0 20.699	6	0.016
7	0 1.150	0 11.006	0 20.863	7	0.019
8	0 1.314	0 11.171	0 21.027	8	0.022
9	0 1.478	0 11.335	0 21.191	9	0.025
10	0 1.643	0 11.499	0 21.356	10	0.027

TABLE III

PART OF TABLE II OF THE AMERICAN NAUTICAL ALMANAC, FOR CHANGING SIDEREAL INTO MEAN SOLAR TIME

(To be subtracted from sideral interval)

Side-real	0^h	1^h	2^h	For Seconds	
m	m s	m s	m s	s	s
0	0 0.000	0 9.830	0 19.659	0	0.000
1	0 0.164	0 9.993	0 19.823	1	0.003
2	0 0.328	0 10.157	0 19.987	2	0.005
3	0 0.491	0 10.321	0 20.151	3	0.008
4	0 0.655	0 10.485	0 20.314	4	0.011
5	0 0.819	0 10.649	0 20.478	5	0.014
6	0 0.983	0 10.813	0 20.642	6	0.016
7	0 1.147	0 10.976	0 20.806	7	0.019
8	0 1.311	0 11.140	0 20.970	8	0.022
9	0 1.474	0 11.304	0 21.134	9	0.025
10	0 1.638	0 11.468	0 21.297	10	0.027

TABLE IV

THE FIRST FEW LINES OF THE SOLAR EPHEMERIS TABLES, WHICH COMPRISE PAGES 400 TO 407 OF THE AMERICAN NAUTICAL ALMANAC

SOLAR EPHEMERIS, 1903. FOR WASHINGTON MEAN AND APPARENT NOON

Date	Apparent Right Ascension		Apparent Declination		Hourly Motion		Equation of Time for Apparent Noon	Semi-Diameter at Apparent Noon	Sidereal Time of Semi-Diameter Passing Meridian	Sidereal Time of Mean Noon
	Mean Noon	App. Noon	Mean Noon	App. Noon	Right Ascension	Declination				
	h m s	s	° ′ ″	″	s	″	m s	′ ″	m s	h m s
Jan. 1	18 44 05.48	6.11	−23 03 44.2	43.6	11.051	+11.64	+3 23.98	16 17.81	1 11.06	18 40 41.57
2	18 48 30.52	31.23	22 58 51.0	50.2	11.037	12.78	3 52.48	16 17.83	1 11.02	18 44 38.12
3	18 52 55.22	56.02	22 53 30.6	29.5	11.022	13.92	4 20.63	16 17.83	1 10.98	18 48 34.68
4	18 57 19.54	20.42	22 47 42.8	41.6	11.005	15.06	4 48.39	16 17.82	1 10.93	18 52 31.24
5	19 01 43.45	44.41	22 41 27.9	26.5	10.987	16.18	5 15.75	16 17.81	1 10.87	18 56 27.80
6	19 06 06.91	7.95	−22 34 46.0	44.4	10.968	+17.30	+5 42.67	16 17.81	1 10.81	19 00 24.35
7	19 10 29.90	31.02	22 27 37.4	35.5	10.948	18.41	6 09.11	16 17.80	1 10.75	19 04 20.91
8	19 14 52.39	53.59	22 20 02.2	0.0	10.926	19.51	6 35.05	16 17.79	1 10.69	19 08 17.47
9	19 19 14.36	15.63	22 11 60.7	58.3	10.903	20.60	7 00.46	16 17.76	1 10.62	19 12 14.02
10	19 23 35.77	37.12	22 03 33.1	30.5	10.880	21.68	7 25.32	16 17.72	1 10.54	19 16 10.58

TABLE V

PART OF THE TABLE OF 383 FIXED STARS, WHICH COMPRISES PAGES 304 TO 311 OF THE AMERICAN NAUTICAL ALMANAC

FIXED STARS, 1903. MEAN PLACES FOR 1903.0 (January 0.826[d], Washington)

Names of Star	Magnitude	Right Ascension	Annual Variation	Declination	Annual Variation
		h m s	s	° ′ ″	″
33 Piscium	4.7	0 00 22.254	+3.0716	− 6 15 00.68	+20.137
δ Piscium	4.8	0 43 38.935	+3.1092	+ 7 03 26.11	+19.640
γ Cassiopeiæ	2.3	0 50 50.911	3.5893	+60 11 29.65	19.550
μ Andromedæ	4.0	0 51 21.986	3.3174	+37 58 23.86	19.575
43 Cephei (H.)	4.6	0 55 23.710	7.4355	+85 44 13.13	19.460
ε Piscium	4.3	0 57 54.479	3.1102	+ 7 22 04.76	19.436
β Andromedæ	2.2	1 04 17.872	+3.3473	+35 06 22.95	+19.146
κ Tucanæ	4.9	1 12 28.743	2.0417	−69 23 29.15	19.142
f Piscium	5.1	1 12 47.697	3.0917	+ 3 06 13.54	19.018
θ′ Ceti	3.6	1 19 10.477	2.9976	− 8 41 01.59	18.647
α Ursæ Minoris (*Polaris*)	2.2	1 23 49.770	25.8359	+88 47 22.84	18.724
β Arietis	2.8	1 49 16.753	3.3061	+20 20 02.47	17.700
50 Cassiopeiæ	4.1	1 55 08.306	5.0381	+71 57 07.60	17.589
γ Andromedæ	2.2	1 57 56.494	+3.6665	+41 51 52.13	+17.400
α Arietis	2.1	2 01 42.178	3.3736	+23 00 14.26	17.142
β Trianguli	3.1	2 03 46.126	3.5578	+34 31 43.16	17.149
ξ′ Ceti	4.5	2 07 51.441	3.1755	+ 8 23 30.46	16.991
γ Trianguli	4.3	2 11 32.693	3.5549	+33 23 55.56	16.782
α Canis Majoris (*Sirius*)	−1.4	6 40 52.425	2.6435	−16 34 58.33	4.764
α Lyræ (*Vega*)	0.2	18 33 39.256	2.0313	+38 41 35.34	3.213

TABLE VI

PART OF THE TABLE GIVING THE EXACT POSITIONS OF 383 FIXED STARS, WHICH COMPRISES PAGES 312 TO 390 OF THE AMERICAN NAUTICAL ALMANAC

FIXED STARS, 1903. APPARENT PLACES FOR THE UPPER TRANSIT AT WASHINGTON

(Constants of Struve and Peters)

Mean Solar Date	α Ursæ Min. (*Polaris*) Right Ascension	α Ursæ Min. (*Polaris*) Declination *North*	Mean Solar Date	α Canis Majoris (*Sirius*) Right Ascension	α Canis Majoris (*Sirius*) Declination *South*	Mean Solar Date	α Lyræ (*Vega*) Right Ascension	α Lyræ (*Vega*) Declination *North*	Mean Solar Date	λ Pegasi Right Ascension	λ Pegasi Declination *North*
	h m	° ′		h m	° ′		h m	° ′		h m	° ′
	1 24	+88 47		6 40	−16 34		18 33	+38 41		22 41	+23 03
Jan.	s	″	Jan.	s	″	Jan.	s	″	Jan.	s	″
0.3	34.40	42.0	0.5	54.19	68.0	1.0	37.86	43.5	1.2	51.39	29.6
				.06	2.3		.11	3.1		.10	1.5
1.3	33.32	42.1	10.5	54.25	70.3	11.0	37.97	40.4	11.1	51.29	28.1
				.01	2.2		.15	3.0		.08	1.6
2.3	32.20	42.2	20.5	54.26	72.5	21.0	38.12	37.4	21.1	51.21	26.5
				.04	2.0		.20	2.9		.06	1.7
3.3	31.10	42.3	30.4	54.22	74.5	30.9	38.32	34.5	31.1	51.15	24.8
			Feb.	.08	1.7	Feb.	.24	2.5	Feb.	.03	1.8
4.3	30.05	42.4	9.4	54.14	76.2	9.9	38.56	32.0	10.1	51.12	23.0
5.3	29.04	42.5					.26	2.1		.01	1.7

TABLE VII

MEAN REFRACTION TO BE APPLIED TO ALL MEASURED ALTITUDES

(*Subtractive from apparent altitude*)

App. Altitude	Refraction	App. Altitude	Refraction	App. Altitude	Refraction	App. Altitude	Refraction	App. Altitude	Refraction
° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″
0 0	33 0			6 40	7 40	10 0	5 15	16 40	3 8
						10 10	5 10	16 50	3 6
		3 30	13 6			10 20	5 5	17 0	3 4
						10 30	5 0	17 10	3 3
				7 0	7 20	10 40	4 56	17 20	3 1
						10 50	4 51	17 30	2 59
						11 0	4 47	17 40	2 57
						11 10	4 43	17 50	2 55
		4 0	11 51	7 20	7 2	11 20	4 39	18 0	2 54
						11 30	4 34	18 10	2 52
						11 40	4 31	18 20	2 51
						11 50	4 27	18 30	2 49
1 0	24 29			7 40	6 45	12 0	4 23	18 40	2 47
						12 10	4 20	18 50	2 46
		4 30	10 48			12 20	4 16	19 0	2 44
						12 30	4 13	19 10	2 43
				8 0	6 29	12 40	4 9	19 20	2 41
						12 50	4 6	19 30	2 40
				8 10	6 22	13 0	4 3	19 40	2 38
						13 10	4 0	19 50	2 37
		5 0	9 54	8 20	6 15	13 20	3 57	20 0	2 35
						13 30	3 54	20 10	2 34
				8 30	6 8	13 40	3 51	20 20	2 32
						13 50	3 48	20 30	2 31
2 0	18 35	5 20	9 23	8 40	6 1	14 0	3 45	20 40	2 29
						14 10	3 43	20 50	2 28
				8 50	5 55	14 20	3 40	21 0	2 27
						14 30	3 38	21 10	2 26
		5 40	8 54	9 0	5 48	14 40	3 35	21 20	2 25
						14 50	3 33	21 30	2 24
				9 10	5 42	15 0	3 30	21 40	2 23
						15 10	3 28	21 50	2 21
		6 0	8 28	9 20	5 36	15 20	3 26	22 0	2 20
						15 30	3 24	22 10	2 19
				9 30	5 31	15 40	3 21	22 20	2 18
						15 50	3 19	22 30	2 17
3 0	14 36	6 20	8 3	9 40	5 25	16 0	3 17	22 40	2 16
						16 10	3 15	22 50	2 15
				9 50	5 20	16 20	3 12	23 0	2 14
						16 30	3 10	23 10	2 13

TABLE VII—*Continued*

App. Altitude	Refraction	App. Altitude	Refraction	App. Altitude	Refraction	App. Altitude	Refraction	App. Altitude	Refraction
° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″	° ′	′ ″
23 20	2 12	26 40	1 53	34 0	1 24	48 0	0 51	68 0	0 23
23 30	2 11	26 50	1 52	34 30	1 23	49 0	0 49	69 0	0 22
23 40	2 10	27 0	1 51	35 0	1 21	50 0	0 48	70 0	0 21
23 50	2 9	27 15	1 50	35 30	1 20	51 0	0 46	71 0	0 19
24 0	2 8	27 30	1 49	36 0	1 18	52 0	0 44	72 0	0 18
24 10	2 7	27 45	1 48	36 30	1 17	53 0	0 43	73 0	0 17
24 20	2 6	28 0	1 47	37 0	1 16	54 0	0 41	74 0	0 16
24 30	2 5	28 15	1 46	37 30	1 14	55 0	0 40	75 0	0 15
24 40	2 4	28 30	1 45	38 0	1 13	56 0	0 38	76 0	0 14
24 50	2 3	28 45	1 44	38 30	1 11	57 0	0 37	77 0	0 13
25 0	2 2	29 0	1 42	39 0	1 10	58 0	0 35	78 0	0 12
25 10	2 1	29 30	1 40	39 30	1 9	59 0	0 34	79 0	0 11
25 20	2 0	30 0	1 38	40 0	1 8	60 0	0 33	80 0	0 10
25 30	1 59	30 30	1 37	41 0	1 5	61 0	0 32	81 0	0 9
25 40	1 58	31 0	1 35	42 0	1 3	62 0	0 30	82 0	0 8
25 50	1 57	31 30	1 33	43 0	1 1	63 0	0 29	83 0	0 7
26 0	1 56	32 0	1 31	44 0	0 59	64 0	0 28	84 0	0 6
26 10	1 55	32 30	1 30	45 0	0 57	65 0	0 26	86 0	0 4
26 20	1 55	33 0	1 29	46 0	0 55	66 0	0 25	88 0	0 2
26 30	1 54	33 30	1 26	47 0	0 53	67 0	0 24	90 0	0 0

TABLE VIII

SUN'S PARALLAX IN ALTITUDE TO BE APPLIED TO ALL MEASURED ALTITUDES OF THE SUN

(Additive to observed altitude)

Altitude Degrees	Parallax Seconds	Altitude Degrees	Parallax Seconds
0	9	54	5
6	9	57	5
12	9	60	4
16	8	63	4
20	8	66	3
25	8	69	3
30	8	72	3
34	7	75	2
36	7	78	2
40	7	81	1
45	6	84	1
48	6	87	0
51	5	90	0

TABLE IX

DIP OF THE HORIZON, TO BE APPLIED TO ALL ALTITUDES MEASURED AT SEA

(Subtractive from observed altitude)

Height Feet	Dip	Height Feet	Dip	Height Feet	Dip
	′ ″		′ ″		′ ″
1	0 59	13	3 32	26	5 0
2	1 23	14	3 40	28	5 11
3	1 42	15	3 48	30	5 22
4	1 58	16	3 55	35	5 48
5	2 11	17	4 2	40	6 12
6	2 24	18	4 9	45	6 34
7	2 36	19	4 16	50	6 56
8	2 46	20	4 23	60	7 35
9	2 56	21	4 29	70	8 12
10	3 5	22	4 36	80	8 46
11	3 15	23	4 42	90	9 18
12	3 24	24	4 48	100	9 48

PRACTICAL ASTRONOMY

(PART 1)

EXAMINATION QUESTIONS

(1) (*a*) What circles on the earth are secondaries to the equator? (*b*) What points are the poles of the equator? (*c*) What other circles on the earth have these same points for their poles? (*d*) What points are the poles of the meridian?

(2) (*a*) How is the angle between two great circles measured? What is the value of the angle between: (*b*) the meridian and the equator? (*c*) the prime vertical and the meridian?

(3) (*a*) What is the polar distance of the vernal equinox? (*b*) What is the declination of the south pole? (*c*) What is the hour angle of the zenith? (*d*) What is the azimuth of the north pole?

(4) (*a*) Through what points does the prime vertical pass? (*b*) The meridian? (*c*) In what direction and from what points is the azimuth measured? (*d*) Hour angles? (*e*) Right ascensions?

(5) (*a*) The sidereal time is 22 hours; what is the hour angle of the equinoctial colure? (*b*) The right ascension of a star is $18^h\ 10^m\ 20^s$; at what sidereal time will it be on the meridian?

(6) (*a*) Describe what is meant by standard time. (*b*) Find the standard time at which the hour angle of the sun is $-3^h\ 30^m$, the equation of time being $-3^m\ 12.4^s$, and the longitude from Greenwich being $+6^h\ 44^m\ 10.7^s$. (*c*) Change August 17, 10 A. M., from civil date to astronomical date.

Ans. $\begin{cases} (b)\ 8^h\ 10^m\ 58.3^s \\ (c)\ \text{Aug. } 16,\ 22^h \end{cases}$

(7) The right ascension of a star is $13^h\ 2^m\ 40.1^s$; at what local mean solar time will this star's hour angle be 6 hours at a station whose longitude is $+1^h\ 7^m\ 3.5^s$, on January 5, 1903? Ans. $0^h\ 6^m\ 0.29^s$

(8) For the time 11 A. M., January 2, 1903, at a station whose longitude is $+3^h\ 58^m\ 55.4^s$, find: (*a*) the right ascension of the sun; (*b*) the declination; (*c*) the right ascension of Vega; (*d*) the declination; (*e*) the equation of time; (*f*) the semi-diameter of the sun.

Ans.
(*a*) $18^h\ 49^m\ 3.43^s$
(*b*) $-22°\ 58'\ 12.9''$
(*c*) $18^h\ 33^m\ 37.87^s$
(*d*) $+38°\ 41'\ 43.2''$
(*e*) $+3^m\ 55.97^s$
(*f*) $16'\ 17.83''$

(9) The altitude of the lower edge of the sun was observed at noon on January 3, 1903, with a transit and mercury horizon at a station whose longitude was $-3^h\ 1^m\ 10^s$, and found to be $20°\ 12'\ 10''$; what was the true altitude of the sun's center? Ans. $+20°\ 26'\ 2.2''$

(10) The wire of a transit was placed tangent to the upper edge of the sun, and the vertical circle was read; it was then placed tangent to the lower edge, and the vertical circle read again; the observations were then repeated on the image of the sun reflected from a mercury horizon. The four readings were: $30°\ 12'\ 10''$, $29°\ 40'\ 50''$, $329°\ 48'\ 0''$, $330°\ 19'\ 30''$. Find the true altitude of the sun's center. Ans. $29°\ 54'\ 52.0''$

(11) The mean solar time at a place whose longitude is $+2^h\ 6^m$ was observed on January 4, 1903, to be $2^h\ 10^m\ 8^s$ P. M.; what was the sidereal time? Ans. $21^h\ 3^m\ 21.317^s$

(12) When a mean-time clock and a sidereal clock both indicate the same time, what is the right ascension of the mean sun?

(13) If the standard central time at a place whose longitude is 85° is $10^h\ 32^m$, what is the local time? Ans. $10^h\ 52^m$

(14) The altitude of a star was observed with a transit having an incomplete vertical circle; the correction for index error was $-1'\ 30''$; the circle reading was $60°\ 40'\ 30''$. Find the true altitude. Ans. $60°\ 38'\ 28''$

Mail your work on this lesson as soon as you have finished it and looked it over carefully. DO NOT HOLD IT until another lesson is ready.


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